NASA TECHNICAL NOTE NASA TN D-5828

NASA TN D-5828

LIFTING ENTRY (L/D ≦ 0.2) FOR UNMANNED VIKING CLASS MARS LANDERS

by E. Brian Pritchard and Edwin F. Harrison

Langley Research Center
Hampton, Va. 23365

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1970

1. Report No. NASA TN D-5828	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LIFTING ENTRY ($L/D \leqq 0.2$) FOR UNMANNED VIKING CLASS MARS LANDERS		5. Report Date June 1970
		6. Performing Organization Code
7. Author(s) E. Brian Pritchard and Edwin F. Harrison		8. Performing Organization Report No. L-7074
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23365		10. Work Unit No. 124-64-04-02-23
		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

An analysis was performed to define the capabilities of lifting-entry vehicles (lift-drag ratio L/D of 0.2 or less) for both the out-of-orbit and direct entry modes for Viking class Mars missions. It is shown that for either out-of-orbit entry or direct entry with approach guidance (entry angle corridor, 3°), use of a vehicle with $L/D \approx 0.1$ provides reductions in parachute deployment conditions, increases in terrain-height allowances, or payload-growth potential in comparison with a ballistic vehicle. An $L/D \approx 0.2$ is required to perform the Viking class mission for direct entry without approach guidance (entry angle corridor, 10°) unless large hypersonic ballutes are to be developed for the ballistic vehicle.

17. Key Words (Suggested by Author(s)) Mars landers; Entry trajectories; Lifting entry vehicles	18. Distribution Statement Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	39	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

LIFTING ENTRY ($L/D \leqq 0.2$) FOR UNMANNED VIKING CLASS MARS LANDERS

By E. Brian Pritchard and Edwin F. Harrison
Langley Research Center

SUMMARY

An analysis was performed to define the capabilities of lifting entry vehicles (lift-drag ratios (L/D) less than or equal to 0.2) for both the out-of-orbit and direct-entry modes for Viking class Mars missions.

By using a typical 1973 Viking vehicle as a reference point, it was shown that for out-of-orbit entry, use of a vehicle with $L/D = 0.1$ provides reductions in parachute deployment conditions, increased terrain height allowances (from 0.7 to 4.6 km), or a payload growth of about 360 kg if an aeroshell diameter of 3.5 m is maintained. For direct entry, it was shown that for present corridor estimates of $\pm 5^{\circ}$, an L/D of 0.2 is required to perform the 1973 Viking mission.

Consideration of approach guidance, resulting in corridors of $\pm 1.5^{\circ}$, again showed the potential of the $L/D = 0.1$ class vehicle. Although the ballistic vehicle would require either an increased aeroshell diameter or a supersonic ballute, the $L/D = 0.1$ vehicle provided reductions in parachute deployment conditions, increased terrain-height allowances (to 3.048 km), or payload growth potential ($\approx$230 kg) for the 3.5-m aeroshell.

INTRODUCTION

The basic problem in using aerodynamic deceleration for Mars soft lander missions is that of achieving sufficiently low velocities at sufficiently high altitudes to allow the terminal descent system to achieve a soft landing. Minimization of range dispersions to allow landing at selected areas is also highly desirable. Several publications (refs. 1 to 6) have demonstrated the effectiveness of lift in alleviating the problems associated with unmanned Mars landers for various atmospheres and mission constraints. They have, however, generally concentrated on lift-drag ratios in the 0.3 to 0.5 range. The present analysis considers low values of lift-drag ratio ($0 \leqq L/D \leqq 0.2$).

The purpose of this paper is to analyze the Mars entry problem for both out-of-orbit and direct-entry modes with emphasis on the use of lift during entry. No lift modulation capability is considered since a simple fixed-attitude system with lift obtained by center-of-gravity offset is adequate for the missions considered.

In order to establish a common base for the comparisons between lifting and ballistic vehicles, a baseline vehicle was assumed which is comparable to the 1973 Viking design described in detail in reference 7. The results were obtained on a high-speed computer by using the well-known entry equations of motions for a point mass entering a spherical nonrotating planet.

SYMBOLS

A	entry capsule base area, m^2
C_D	drag coefficient
d	vehicle base diameter, m
G_{max}	maximum deceleration load
g_e	acceleration due to gravity at Earth's surface, m/s^2
h	altitude, km
h_d	altitude at parachute deployment, km
h_t	terrain height above mean surface, km
L/D	lift-drag ratio
M	Mach number
M_d	Mach number at parachute deployment
m/A	wing loading, kg/m^2
m/C_DA	ballistic coefficient, kg/m^2
Q_c	convective heating load, J/m^2
$\dot{q}_c$	convective heating rate, J/m^2-s
q_d	dynamic pressure at parachute deployment, N/m^2

V	velocity, km/s
V_e	entry velocity, km/s
$(m/m_o)_{hs}$	ratio of heat-shield weight to 3.5-meter-diameter heat-shield weight
Z	center-of-gravity offset, cm
γ	flight-path angle, deg
γ_e	entry flight-path angle, deg
$\Delta\gamma_e$	entry corridor, deg

MODEL ATMOSPHERES

The Mars atmospheres used in this study represent the best atmospheric data available prior to the Mariner 6 and 7 missions and are given in figure 1 and table I. Comparison of these models with a preliminary atmospheric model based on Mariner 6 and 7 results indicated that the results obtained in this study do not differ appreciably. Thus, the validity of the present results are not altered by the Mariner 6 and 7 data.

OUT-OF-ORBIT ENTRY

Baseline Characteristics

The baseline vehicle selected for the out-of-orbit analysis is comparable to the Viking 1973 vehicle (ref. 7) and has the following characteristics:

Shape	140^{o} blunted cone
Baseline diameter	3.5 m
Entry mass	731 kg
L/D	0
m/A	76 kg/m^2

The ballistic coefficient m/C_DA associated with values of L/D of up to 0.3 may be obtained with the aid of figure 2 (taken from ref. 8).

The baseline mission characteristics associated with this system for the 1973 mission are:

Entry velocity	4.6 km/s
Entry altitude	244 km
Entry corridor	-14^{o} to -18^{o} (includes 2.6^{o} for targeting and 1.4^{o} for trajectory errors)

The combination of these vehicle and mission characteristics results in the following baseline parachute deployment conditions for entry at the steep-corridor boundary (-18°) in the minimum scale height atmosphere:

M_d 2
q_d . . . . 624 N/m^2
h_d . . . . 5.1 km

Parachute Deployment Conditions

Lift can be used for the present 1973 vehicle design to alleviate parachute deployment conditions as shown in figure 3. Little reduction in M_d is indicated by increasing L/D much beyond 0.1. A factor of major importance – terrain height (that is, elevation above mean surface) – is also shown here. For the type of system considered, about 4.4 km is required for the parachute and retro systems to decelerate the vehicle to a soft landing. Thus, the altitude available for terrain-height accommodation must be measured from a base of 4.4 km. With L/D = 0.1, the terrain height can be increased from 0.7 to 1.9 km while decreasing parachute deployment conditions to $M_d = 1.5$ and $q_d \approx 300$ N/m^2, these values being significant reductions from the baseline design point. The maximum gain in terrain height due to increased L/D is shown in figure 4 for a deployment Mach number of 2 (4.6-km terrain height is available for L/D = 0.1). The associated deployment dynamic pressures are also given in figure 4.

The baseline 1973 mission design calls for an entry corridor capability of -14° to -18° which includes an allowance for entry errors of $\pm 0.7^{\circ}$ and a targeting allowance of 2.6°. As shown in figure 5, the ballistic vehicle has no terrain-height capability for entry angles steeper than about -18.5°. Use of a vehicle with L/D = 0.1 allows entry at somewhat steeper angles while maintaining a reasonable terrain-height capability.

Range and Time Dispersion

Range dispersion is defined as the maximum difference in longitudinal range obtained during entry at the corridor boundaries including the effects of the uncertainty in atmosphere. For the nominal out-of-orbit entry $\left(\gamma_e = -16^{\circ} \pm 0.7^{\circ}\right)$, the range dispersion is presented in figure 6. As indicated, the use of lift results in only small increases in range dispersion (≈5 percent for L/D = 0.1).

Since the 1973 mission uses a relay communications mode during entry, the time dispersion associated with the range dispersion is also of interest in that it restricts the orbiter-lander trajectory geometry. Figure 6 shows that the use of lift up to L/D = 0.2 has little effect on time dispersion. It should be pointed out that reductions in both range and time dispersions can be obtained with lifting entry since such vehicles have the capability of entry at steeper flight-path angles than the ballistic vehicle. (See fig. 5 and ref. 6.)

Roll-Angle Bias Effects

One factor of importance to the practicality of lifting entry is that of roll-angle bias which may occur because of drift errors in the inertial guidance system, and so forth. It is therefore necessary to define the effects of roll-angle bias on lifting entry in terms of parachute deployment conditions and range dispersions. For a vehicle with $L/D = 0.1$, the terrain-height capability for Mach 2 parachute deployment is presented in figure 7 for roll-angle bias up to 90°. Little degradation is obtained for bias of 30° or less and even at 45° the terrain-height capability is about 3.4 km.

The effects of roll-angle bias on longitudinal and lateral range measured from the point of entry are given in figure 8 for the same conditions. As expected, the longitudinal range is only slightly decreased and maximum lateral dispersions are small ($\approx 0.5^{\circ}$).

The problem of roll-angle uncertainty can be critical to the success of a mission as illustrated in figure 9. If center-of-gravity offsets occur and result in angles of attack greater than about 1.25°, the entry vehicle may not survive landing as evidenced by the 180° roll-angle curve. Since some center-of-gravity offset is likely to occur even for a ballistic design, the roll angle will probably be controlled during entry to eliminate the possibility of attaining a negative lift condition during entry.

Heating and Deceleration Characteristics

In order to evaluate completely the capabilities and penalties associated with lifting entry, it is necessary to consider the effects of lift on both aerodynamic heating and deceleration loads. Figure 10 presents the stagnation-point maximum heating rates and loads (based on a nose radius of 0.3048 m) and the peak deceleration loads encountered during entry in the -14° to -18° entry corridor. For L/D up to 0.1, little effect is shown in heating rate but an increase in total heat load of about 10 percent is obtained. The peak deceleration load however is decreased somewhat.

It appears, on the basis of figure 10, that little penalty is associated with the use of $L/D = 0.1$ in terms of heat-shield and structural weights. Since the thermal and structural loads are asymmetric, a detailed analysis is required to define any such weight penalties.

Growth Potential

The possibility of Viking class missions in 1975 and 1977 raises the question of growth potential for the present system. For the present parachute deployment conditions $\left(M_d = 2 \text{ at } 5.1 \text{ km}\right)$, the payload growth potential or excess weight capability above the 1973 mission design is shown in figure 11. Increasing L/D to about 0.08 results in a growth potential to about 360 kg. For $L/D > 0.08$, the vehicle m/A which can satisfy the terminal constraints is greater than that which can be packaged. The shaded

area (fig. 11) indicates the region of packaging uncertainty; real limits could only be obtained by a series of point designs.

DIRECT ENTRY

The use of the direct-entry mode eliminates the requirement of carrying the entry vehicle into orbit and, hence, results in increased weight available for the entry vehicle. However, a much larger entry corridor ($\approx \pm 5^{\circ}$) is required to allow for trajectory errors. The nominal entry velocity of 5.7 km/s selected for this study is representative of the velocities associated with direct-entry unmanned Mars missions. The same baseline vehicle is used for direct entry as for out-of-orbit entry with a weight increase of 113 kg to accommodate the higher entry velocity. This weight increase results in an m/A of 88 kg/m^2 for the direct-entry baseline vehicle.

Parachute Deployment Conditions

If the present 1973 vehicle design is increased by 113 kg to account for the increased heating and structural loads, figure 12 indicates that the ballistic vehicle cannot perform the mission without either deployment of a hypersonic ballute or an increase in diameter. In fact, $L/D \approx 0.2$ is required for the direct-entry mission with the present terminal descent system. Note, however, that the deployment dynamic pressure is somewhat less than that for the ballistic out-of-orbit mission.

The aeroshell diameter increase required to reduce the deployment conditions to the nominal 1973 conditions is indicated in figure 13 where a 4.9-m aeroshell is required for the ballistic vehicle. A rough approximation of the increase in aeroshell weight associated with this diameter increase is given in figure 14 where it is assumed that the aeroshell weight increases as the square of the diameter. For direct entry, this estimate is probably too low since turbulent flow and an associated increase in heating will probably occur at diameter stations greater than about 3.5 m.

Because of the large entry corridor requirements, it has been proposed that approach guidance be used for direct entry. If it is assumed that use of approach guidance will result in corridors of $\pm 1.5^{\circ}$ without a targeting allowance, figure 15 may be used to define nominal values of γ_e for any of several constraints. Since the direct-entry vehicle based on the baseline 1973 design requires an m/A of about 0.88 kg/m^2, the parachute-deployment altitude constraint must be relaxed for the ballistic vehicle, even with approach guidance. Therefore, the ballistic vehicle with a corridor of $\gamma_e = -18.5^{\circ} \pm 1.5^{\circ}$ would have parachute deployment below 4.4 km which is not adequate for the terminal descent phase. As is obvious from figure 15, the lifting vehicles can use shallow corridors ($-19.5^{\circ} \pm 1.5^{\circ}$) to alleviate parachute deployment conditions or to obtain

maximum potential in payload growth. The lifting vehicles can also use steep corridors $\left(\gamma_e = -22.5^\circ \pm 1.5^\circ \text{ for } L/D = 0.1 \text{ and } \gamma_e = -28.5^\circ \pm 1.5^\circ \text{ for } L/D = 0.2\right)$ to achieve minimum range dispersions and total heat loads.

The alleviation of the parachute-deployment-conditions aspect of approach guidance is shown in figure 16. As was the case for the out-of-orbit mode, little is gained in reduction of M_d by increasing L/D beyond 0.1. The reductions in q_d obtained by increasing L/D (fig. 17) are significant for the direct-entry case as well as for the out-of-orbit case. A 40-percent reduction in q_d is indicated by increasing L/D to 0.1.

Range and Time Dispersion

Direct-entry range dispersion is shown in figure 18 to be excessive for reasonable landing-site selection for the $\pm 5^\circ$ entry corridor case although it is not a strong function of L/D in the range considered. The use of approach guidance reduces range dispersions to the order of those obtained for out-of-orbit entry. In particular, use of steep corridors $\left(\text{limited by } M_d = 2\right)$ results in smaller range dispersions than those obtained for out-of-orbit entry. The time dispersions associated with the range dispersions are shown in figure 19. The terrain-height capability achievable with lifting entry is shown to be about 3 km for $L/D = 0.1$ in figure 17 as opposed to the 4.6 km obtained for out-of-orbit entry.

Roll-Angle-Bias Effects

The effects of roll-angle bias during direct entry are similar to those obtained for out-of-orbit entry. The representative case considered is direct entry with approach guidance and $L/D = 0.1$, and results in a maximum entry angle of -21°. Roll-bias effects on parachute deployment altitude are presented in figure 20. A bias of 30° results in a reduction in terrain-height capability of about 0.7 km and a bias of about 71° can be tolerated for a zero terrain-height capability. However, there should be no problem in controlling the roll angle within bounds of $\pm 30^\circ$.

Figure 21 shows that roll-angle bias has little effect on longitudinal range (as one would expect from fig. 18) and the lateral range is comparable to that obtained for the out-of-orbit analysis.

Heating and Deceleration Characteristics

As for out-of-orbit entry, the heating and deceleration characteristics for lifting entry must be defined in order to present a complete analysis for direct entry. Stagnation-point heating rates and loads and peak deceleration loads are presented in figure 22 for direct entry without approach guidance, direct entry with approach guidance

and low entry angles for minimization of the terminal descent problem, and direct entry with approach guidance and high entry angles for minimization of range dispersion.

Without approach guidance, heating rates are reduced by about 18 percent, heating loads are increased by about 16 percent, and deceleration loads are reduced by about 42 percent by increasing L/D from 0 to 0.2. A detailed thermal and structural analysis is, of course, required in order to define any weight penalties for the L/D = 0.2 vehicle. It would appear, however, that the large reduction in structural loading might offset the increased heat load and asymmetrical heating and loading problems.

Use of approach guidance with shallow entry corridors results in little difference in any of the parameters considered in figure 22. Steep corridors, however, result in large increases in heating rates and deceleration loads and an associated reduction in total heat load. On the surface, it would appear that the reduction in range dispersions may well result in significant increases in structural weights and a change in heat-shield-material selection.

Growth Potential

The growth potential for the direct-entry mode is indicated in figure 23 with the same restrictions on parachute deployment conditions ($M_d = 2$ at 5.1 km) and vehicle diameter (3.5 m) as were used for the out-of-orbit analysis. As shown, an L/D of 0.17 is required to perform the 1973 mission without approach guidance and an L/D of 0.04 is required with approach guidance. Potential payload growth increases rapidly to the approximate packaging constraint in both cases with about 160 kg to 250 kg of growth available for later missions depending on lift-drag ratio and guidance.

GENERAL CONSIDERATIONS

Dynamic Pressure

It has been pointed out that the parachute deployment dynamic pressure can be reduced by use of lifting entry. By following the analysis of reference 6, parachute system weights were defined for a range of dynamic pressures. The results presented in figure 24 illustrate that the parachute system masses can be reduced by as much as 10 kg for the 1973 baseline vehicle by the use of a lifting entry vehicle (L/D = 0.1).

Terminal Descent Mode

One might presume that an all-propulsive terminal descent mode might be more efficient than the parachute-propulsion mode for the direct-entry lifting vehicle because of the lower velocities associated with the lifting-terminal-descent initiation. Table II which was obtained by the methods of reference 6 shows that this is not the case. In fact,

use of all-propulsive mode would result in a weight penalty of 34 kg. Additional problems are also introduced. The burn must be initiated at low supersonic speeds ($M \approx 1.2$); radar acquisition is difficult because of initially low flight-path angles ($\approx -25^{\circ}$); and means must be developed to either separate the aeroshell from the lander or deploy external landing legs.

Center-of-Gravity Offset Requirements

The center-of-gravity offset required to achieve a lifting capability with a 140° blunted cone are presented in figure 25 (from ref. 8) where it is assumed that the center of gravity lies along the baseline of the vehicle. Actually, the center of gravity will probably lie slightly aft of the baseline in the final design. This position will result in a slightly smaller offset for a given L/D capability. In any case, the center-of-gravity offset requirements for a 3.5-m-diameter vehicle are on the order of 2 to 5 cm and should not present any major design problems.

Mars Atmosphere Surface Pressure

The Martian atmosphere is still not well defined although the Mariner 6 and 7 results indicate a probable range of surface pressure of 400 N/m^2 to 1000 N/m^2. It is, therefore, desirable to define the effects of any changes in our knowledge of the Martian atmosphere on the payload growth potential of ballistic and lifting entry vehicles. The results of an approximate analysis is shown in figure 26 where it was assumed that the scale height of model atmosphere A (table I and fig. 1) remained constant but the surface pressure was allowed to increase from 400 N/m^2 up to 1000 N/m^2. As shown, direct ballistic entry without approach guidance would yield about a 80-kg payload growth capability if the surface pressure is 1000 N/m^2. At 600 N/m^2, the ballistic vehicle provides about 270 kg of growth for direct entry with approach guidance and about 360 kg for out-of-orbit entry. A vehicle with $L/D = 0.1$ provides about 55 kg of growth for direct entry without approach guidance at 600 N/m^2. The previously discussed 400 N/m^2 case obviously requires lift for growth and it is significant to note that a lifting vehicle provides large growth capability even in the 300 N/m^2 range of surface pressure.

Lifting Vehicle Problem Areas

Since the center-of-gravity offset requirement is small, it appears that the only unique problems associated with the low L/D lifting vehicle are the asymmetrical heating and loading problems. These problems may result in some increases in heat shield and structural weights which, however, should not be significant. In addition, the effect of asymmetrical heat-shield ablation for the direct-entry case should be studied to determine the extent of any center-of-gravity shift due to the loss of heat-shield material.

CONCLUSIONS

This study has demonstrated that there are many advantages to the use of lifting entry at Mars for both out-of-orbit and direct entry missions. Some of those benefits are listed.

Out-of-Orbit Entry

1. Use of lift (lift-drag ratio of ≈ 0.1) allows
   - (a) reduction in deployment Mach number from 2 to 1.4, reduction in deployment dynamic pressure from 580 to 300 N/m^2, or reduction in parachute weight by 10 kg
   - (b) increased growth potential of ≈ 360 kg for a deployment Mach number of 2 and a deployment altitude of 5.1 km
   - (c) increased terrain-height allowances from 0.7 km (for zero lift-drag ratio) to 4.6 km with a deployment Mach number of 2.
2. Lifting entry (lift-drag ratio of ≈ 0.1) results in small range and time dispersions.

Direct Entry Without Approach Guidance

1. A zero lift-drag ratio requires either hypersonic ballute deployment or a diameter increase to ≈ 5 m.

2. A lift-drag ratio of ≈ 0.2 is required to perform the 1973 mission and has a payload growth potential of ≈ 160 kg for a base diameter of 3.5 m for a deployment Mach number of 2.

3. Range dispersions ($\approx 27^{\circ}$) are excessive for reasonable landing site selection.

Direct Entry With Approach Guidance

1. Ballistic vehicle requires either increased diameter or ballute deployment at high supersonic speeds.

2. Use of lift (lift-drag ratio of ≈ 0.1) allows
   - (a) parachute deployment at a Mach number of 1.6 and a dynamic pressure of 330 N/m^2,
   - (b) payload growth potential of 230 kg for a deployment Mach number of 2, or
   - (c) increased terrain-height allowances (3 km).

3. Range dispersions are of the same order as for out-of-orbit entry.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 20, 1970.

REFERENCES

1. Pritchard, E. Brian; and Harrison, Edwin F.: Analysis of Mars Entry With Consideration of Separation and Line-of-Sight Relay Communications for Bus-Capsule Combinations. NASA TN D-2841, 1965.
2. McLellan, Charles H.; and Pritchard, E. Brian: Use of Lift To Increase Payload of Unmanned Martian Landers. J. Spacecraft Rockets, vol. 3, no. 9, Sept. 1966, pp. 1421-1425.
3. Pragluski, William J.: Flight Mechanics of Unmanned Landers. AIAA/AAS Stepping Stones to Mars Meeting, Mar. 1966, pp. 107-115.
4. Pritchard, E. Brian; and Harrison, Edwin F.: Multipurpose Entry Vehicle Requirements for Unmanned Landings on Bodies Having Tenuous Atmospheres. J. Spacecraft Rockets, vol. 5, no. 4, Apr. 1968, pp. 413-418.
5. Pritchard, E. Brian; and Harrison, Edwin F.: Direct Entry Longitudinal Range Dispersion of Unmanned Mars Landers. J. Spacecraft Rockets, vol. 5, no. 12, Dec. 1968, pp. 1497-1498.
6. Harrison, Edwin F.; and Slocumb, Travis H., Jr.: Evaluation of Entry and Terminal Deceleration Systems for Unmanned Martian Landers. Paper presented at AIAA Entry Vehicle Systems and Technology Conference (Williamsburg, Va.), Dec. 1968. (Also J. Spacecraft Rockets, vol. 6, no. 10, Oct. 1969, pp. 1109-1113.)
7. Viking Project Management: 1973 Viking Voyage to Mars. Astronaut. Aeron., vol. 7, no. 11, Nov. 1969, pp. 30-59.
8. Campbell, James F.; and Howell, Dorothy T.: Supersonic Lifting Capabilities of Large-Angle Cones. NASA TN D-5499, 1969.

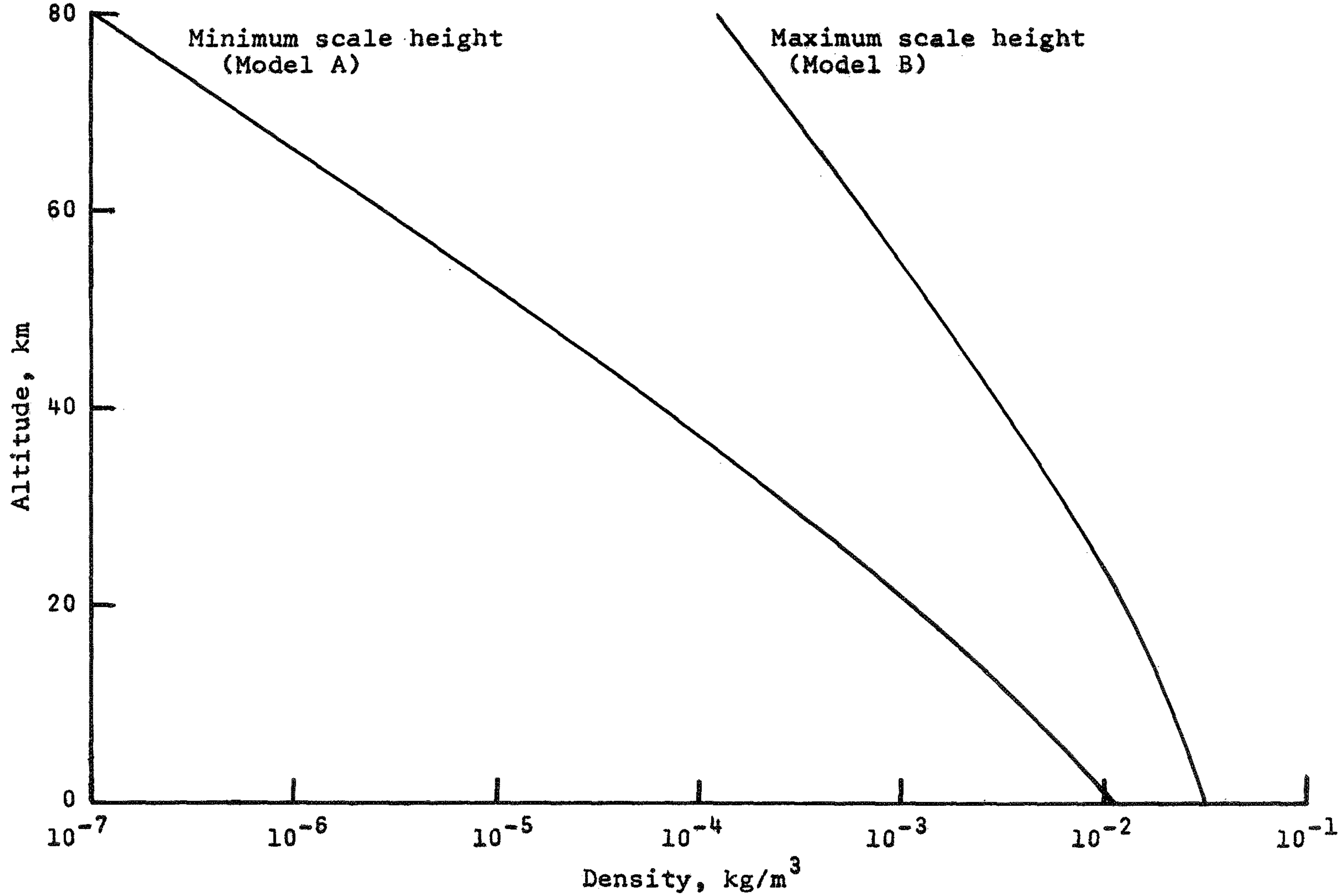
TABLE I.- MARS MODEL ATMOSPHERE

Parameter	Model A minimum scale height	Model B maximum scale height
Surface pressure, N/m^2	400	2000
Surface temperature, ^oK	180	280
Surface density, kg/m^3	1.2×10^{-2}	2.9×10^{-2}
Composition by volume, percent		
CO_2	100	19
N_2	0	60
Ar	0	21
Molecular mass, kg/kg-mole	44	33.6

TABLE II.- TERMINAL DESCENT SYSTEMS

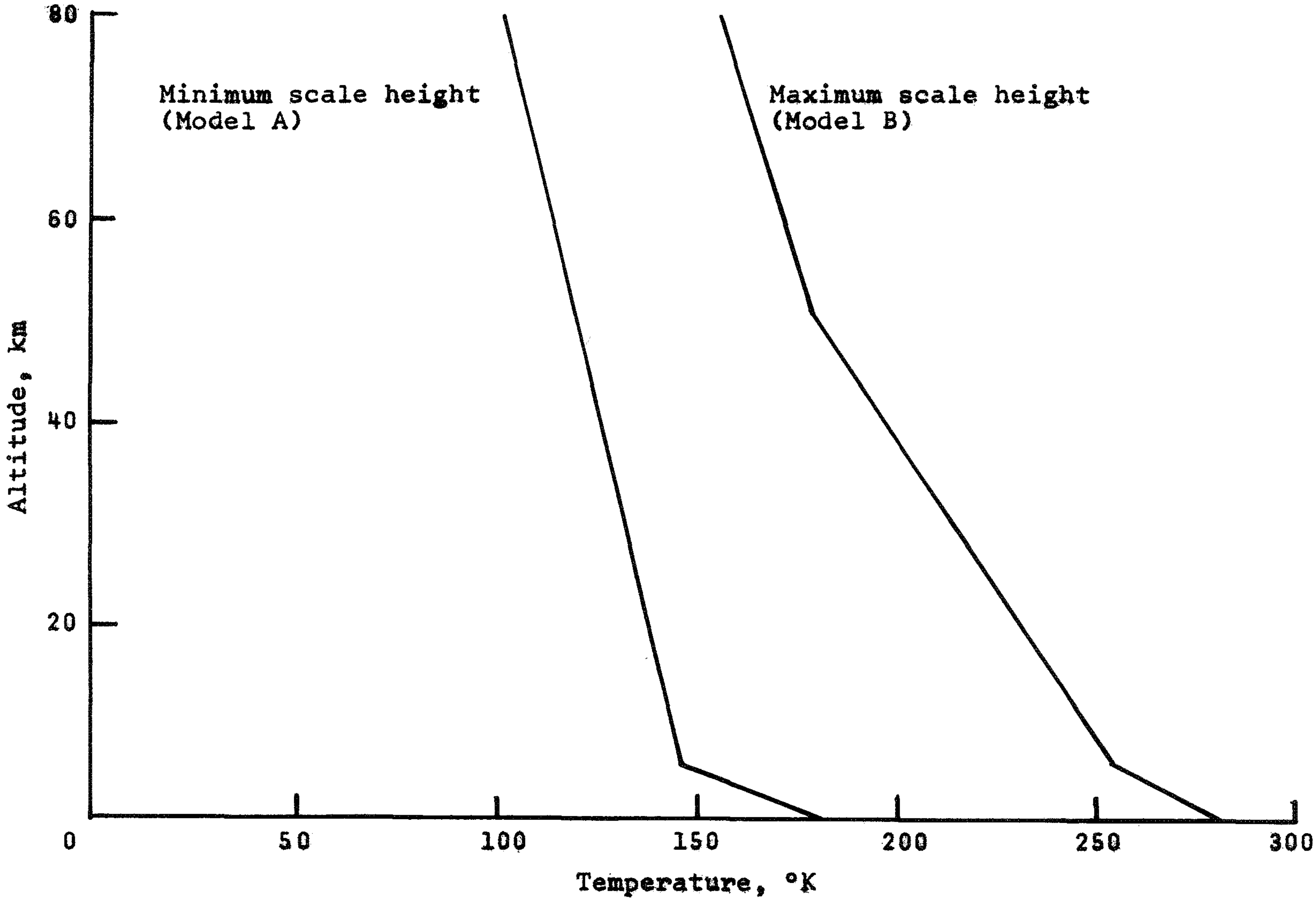
[Direct, lifting entry, $m/A = 88\ kg/m^2$]

	Parachute propulsion	All propulsion
Parachute deployment conditions:		
h_d, km	6.3	----
M_d	1.6	----
q_d, N/m^2	340	----
Propulsion initiation conditions:		
h, km	1.2	4.6
V, m/sec	90	280
γ, deg	75	25
Required thrust, N	6400	6700
Parachute system mass, kg	32	0
Propulsion system mass, kg	98	164
Total system mass, kg	130	164



(a) Density profiles.

Figure 1.- Mars atmospheres.



(b) Temperature profiles.

Figure 1.- Concluded.

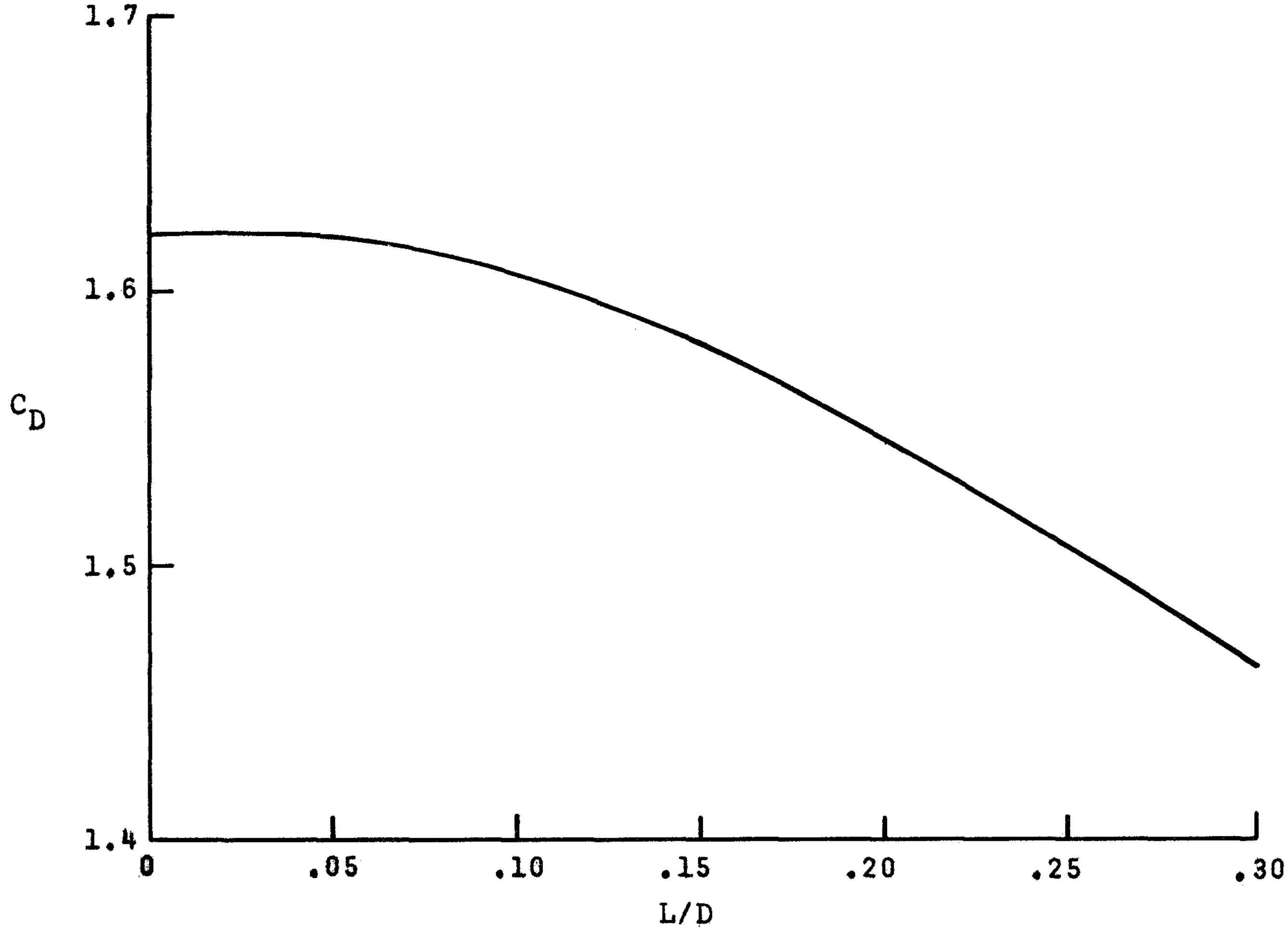


Figure 2.- Hypersonic drag coefficient as a function of L/D for 140° blunted cone. (Plot taken from ref. 8.)

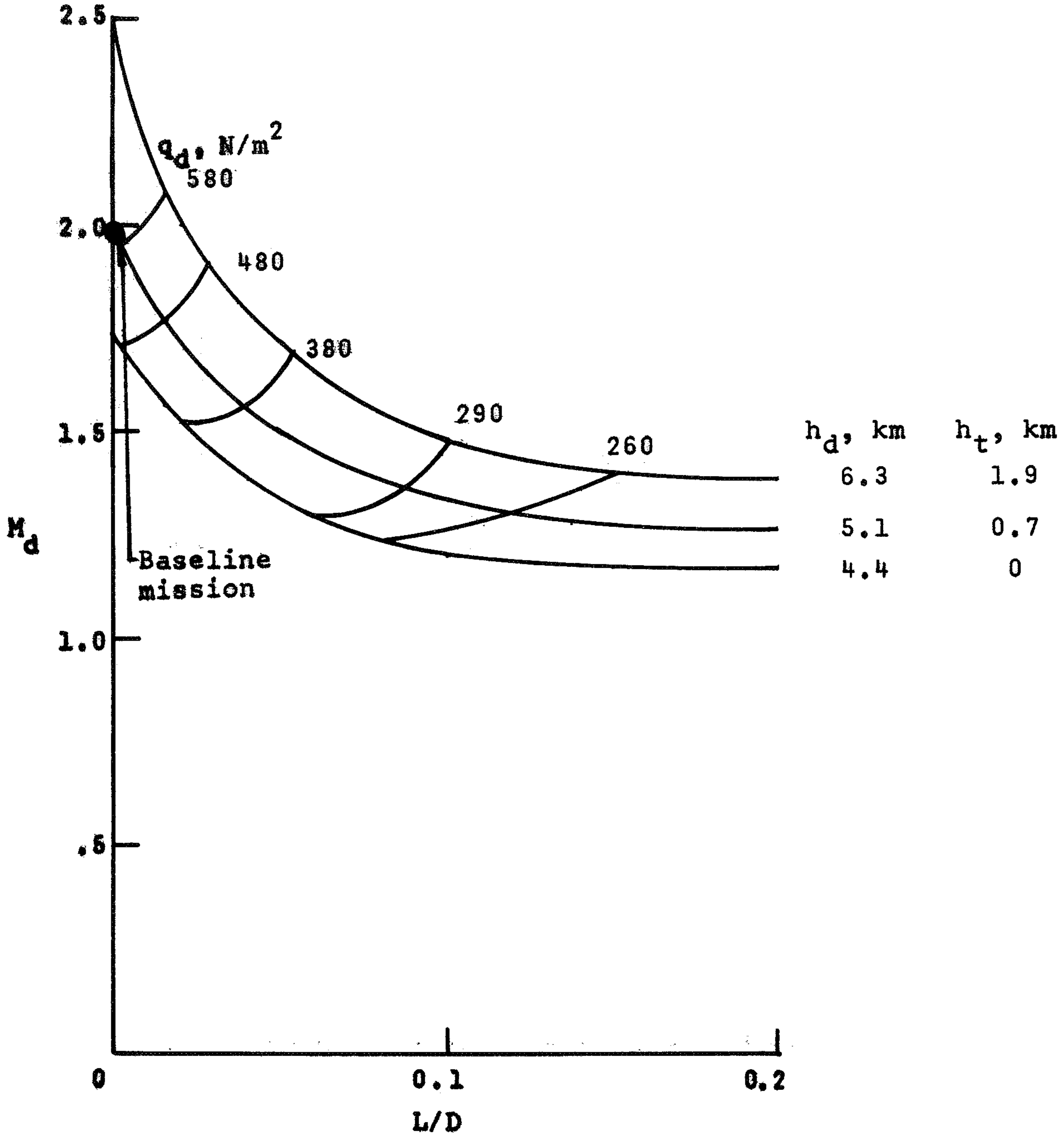
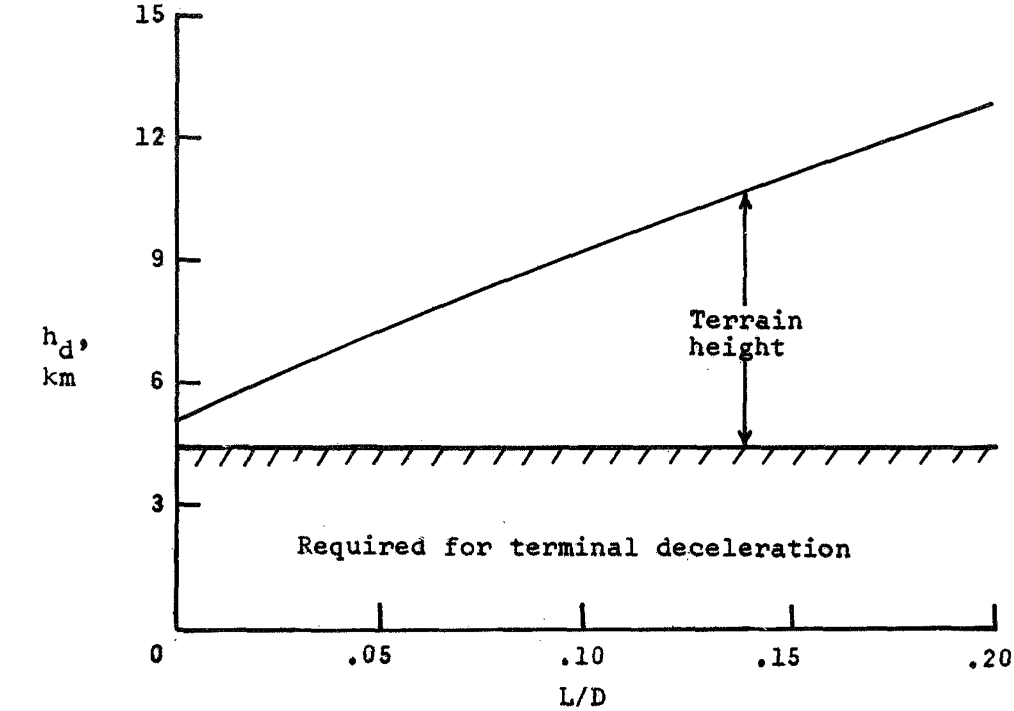
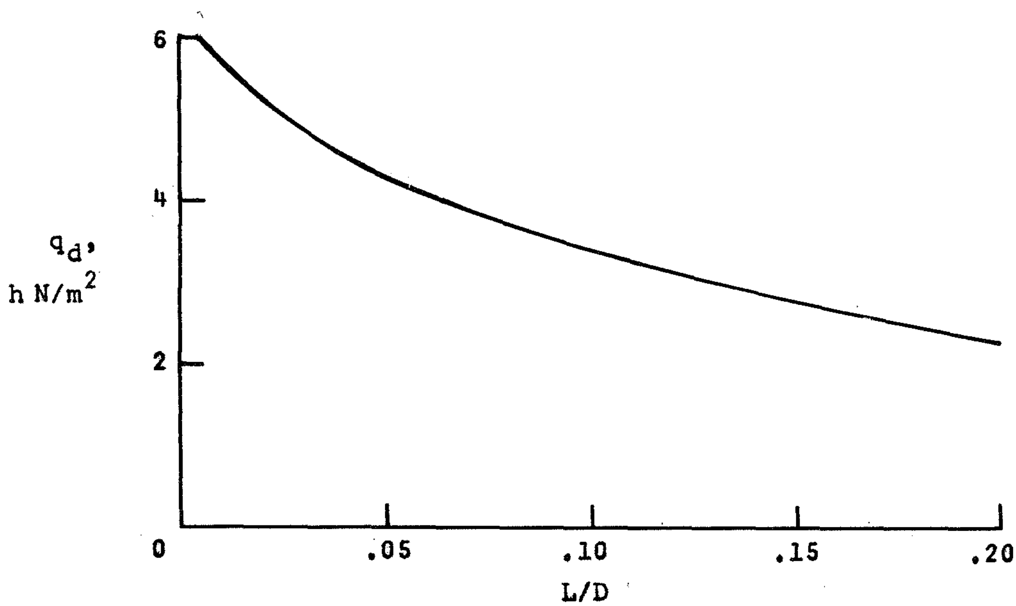


Figure 3.- Parachute deployment conditions for out-of-orbit entry. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; m/A = 76 kg/m^2; model A atmosphere.



(a) Maximum terrain altitude.



(b) Dynamic pressure at maximum altitude.

Figure 4.- Maximum terrain-height capability with corresponding dynamic pressure for parachute deployment at a Mach number of 2 during out-of-orbit entry. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; m/A = 76 kg/m^2; model A atmosphere.

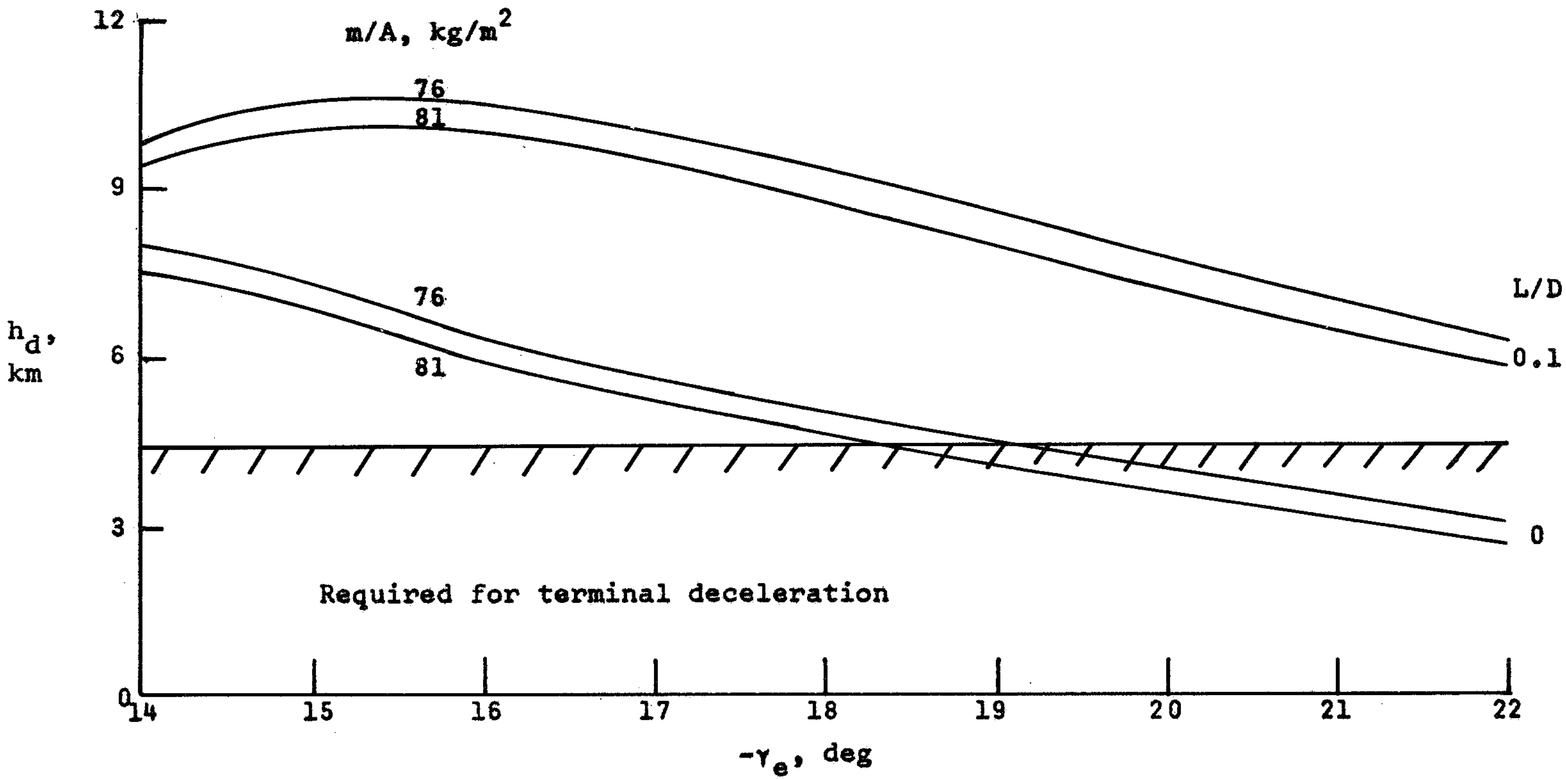


Figure 5.- Effect of entry angle on parachute deployment altitude for out-of-orbit entry. V_e = 4.6 km/s; M_d = 2; model A atmosphere.

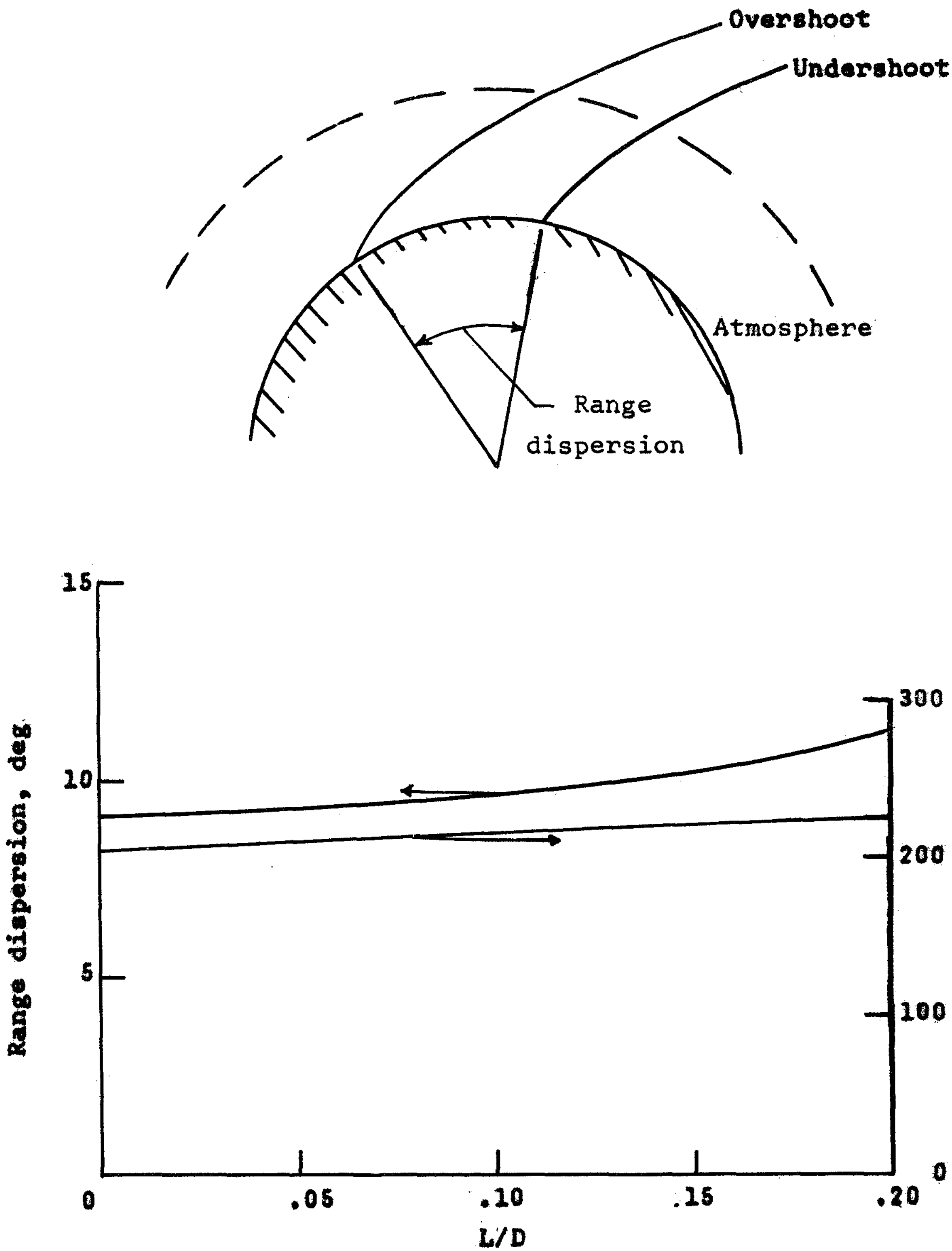


Figure 6.- Out-of-orbit range and time dispersions. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 0.7^0$; m/A = 76 kg/m^2.

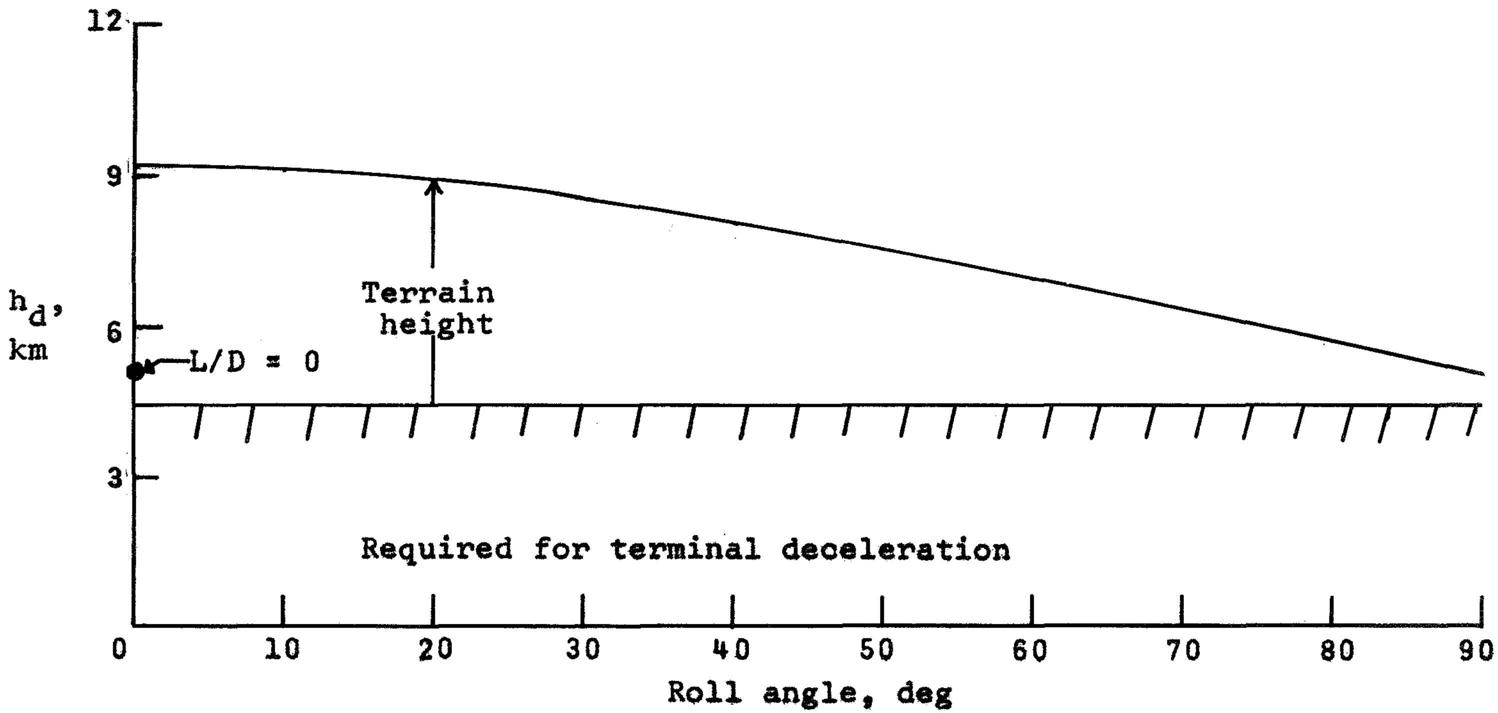


Figure 7.- Effect of roll angle on parachute-deployment altitude for out-of-orbit entry. L/D = 0.1; V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; m/A = 76 kg/m^2; M_d = 2; model A atmosphere.

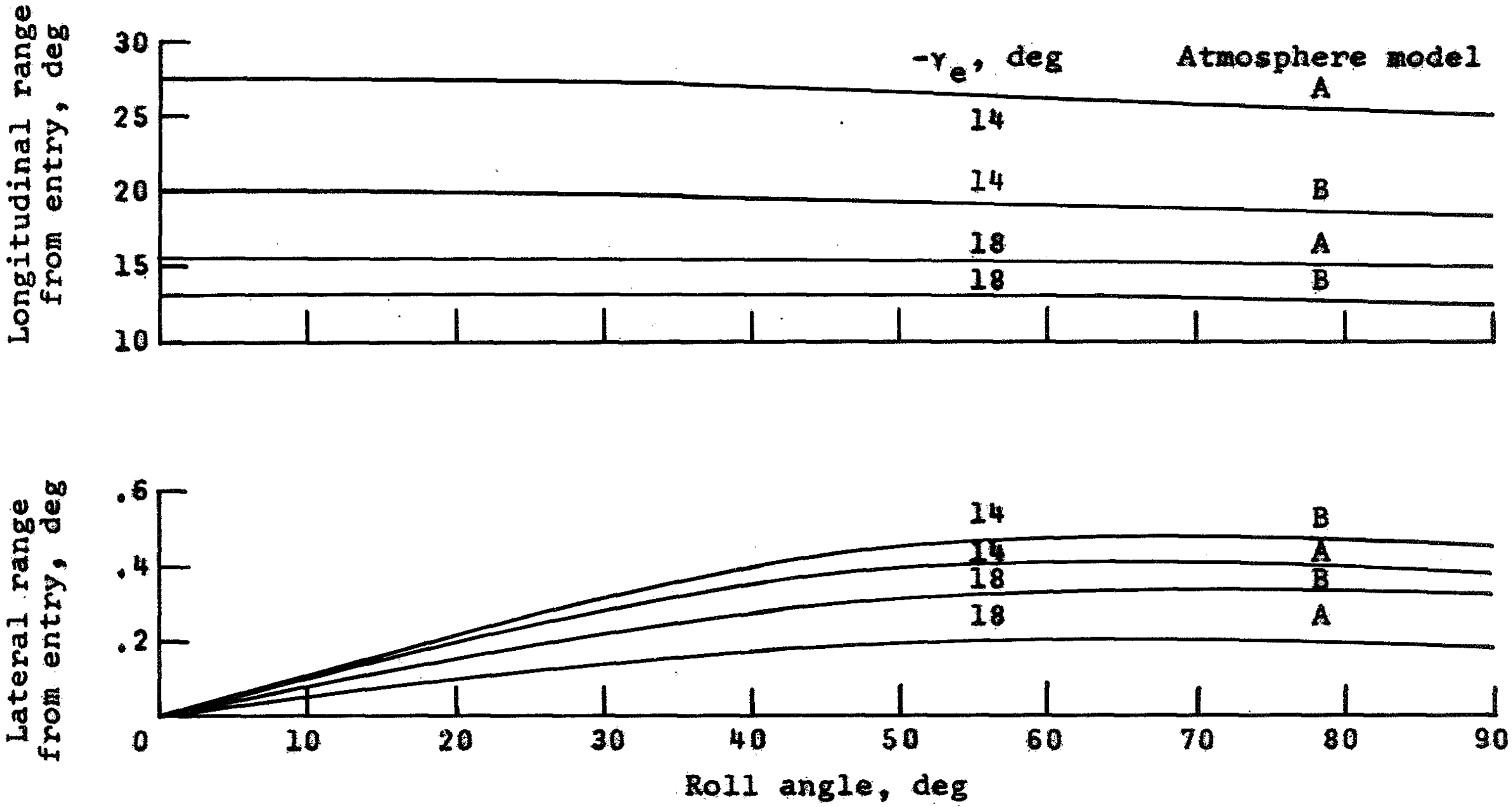


Figure 8.- Effect of roll angle on range for out-of-orbit entry. L/D = 0.1; V_e = 4.6 km/s; m/A = 76 kg/m^2.

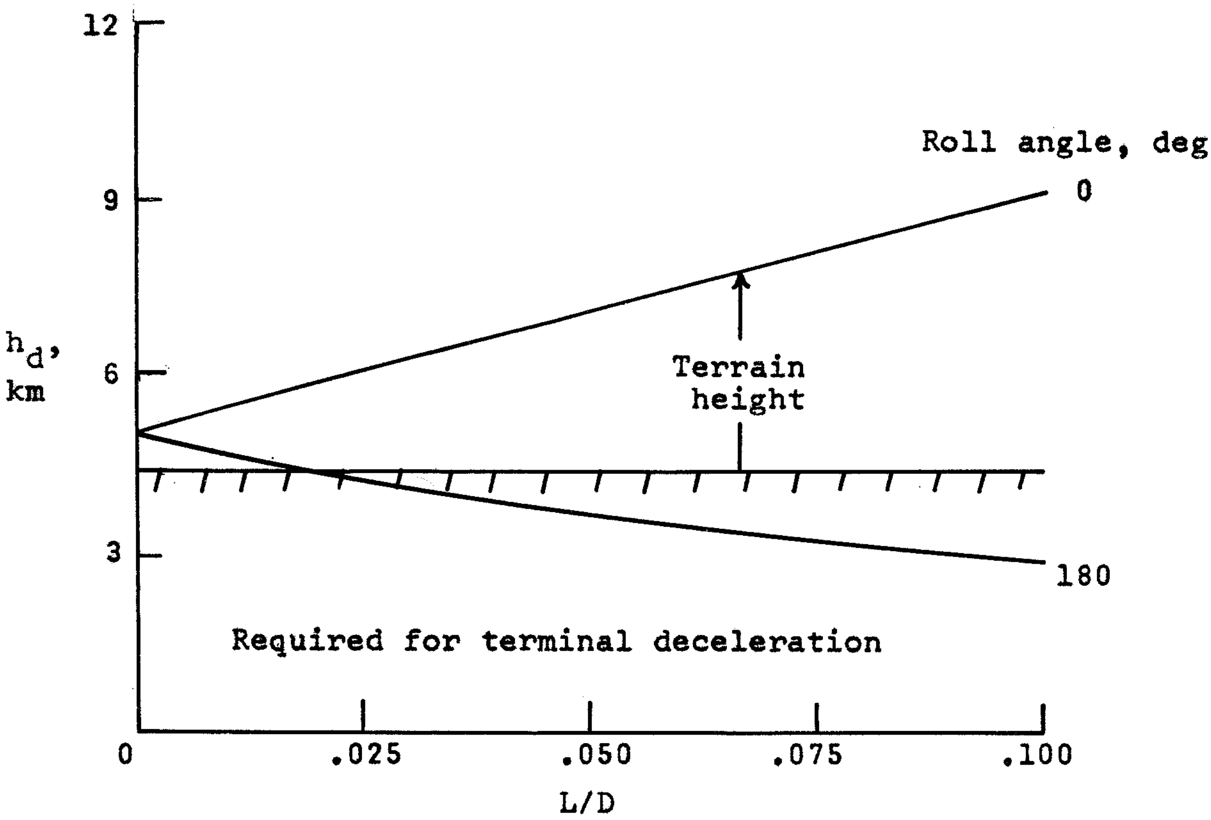


Figure 9.- Effect of extreme roll angles on parachute-deployment altitude for out-of-orbit entry. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; M_d = 2; m/A = 76 kg/m^2; model A atmosphere.

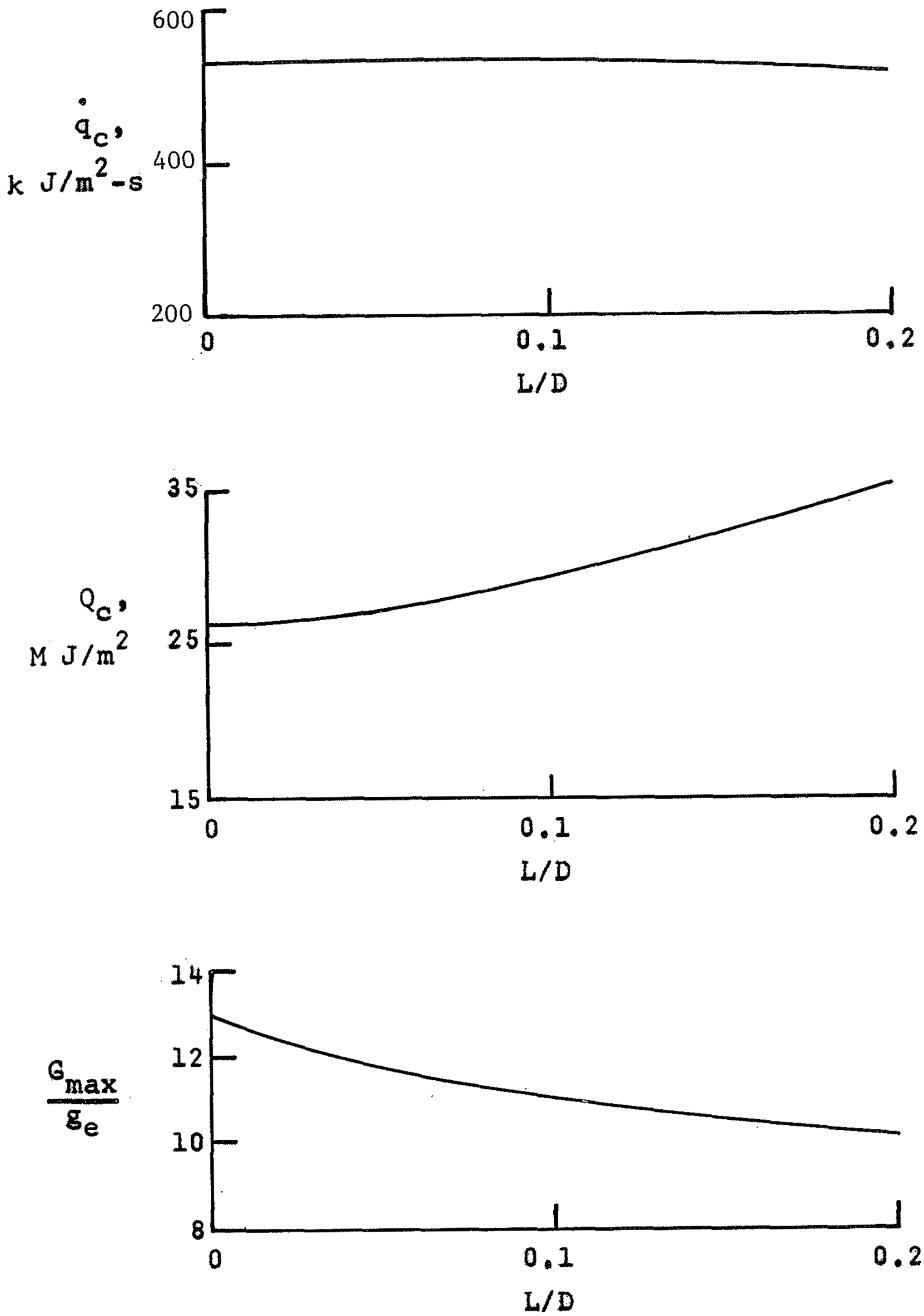


Figure 10.- Heating and deceleration characteristics for out-of-orbit entry. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; m/A = 76 kg/m^2; model A atmosphere for $\dot{q}_c$ and G_{max}/g_e and model B atmosphere for Q_c.

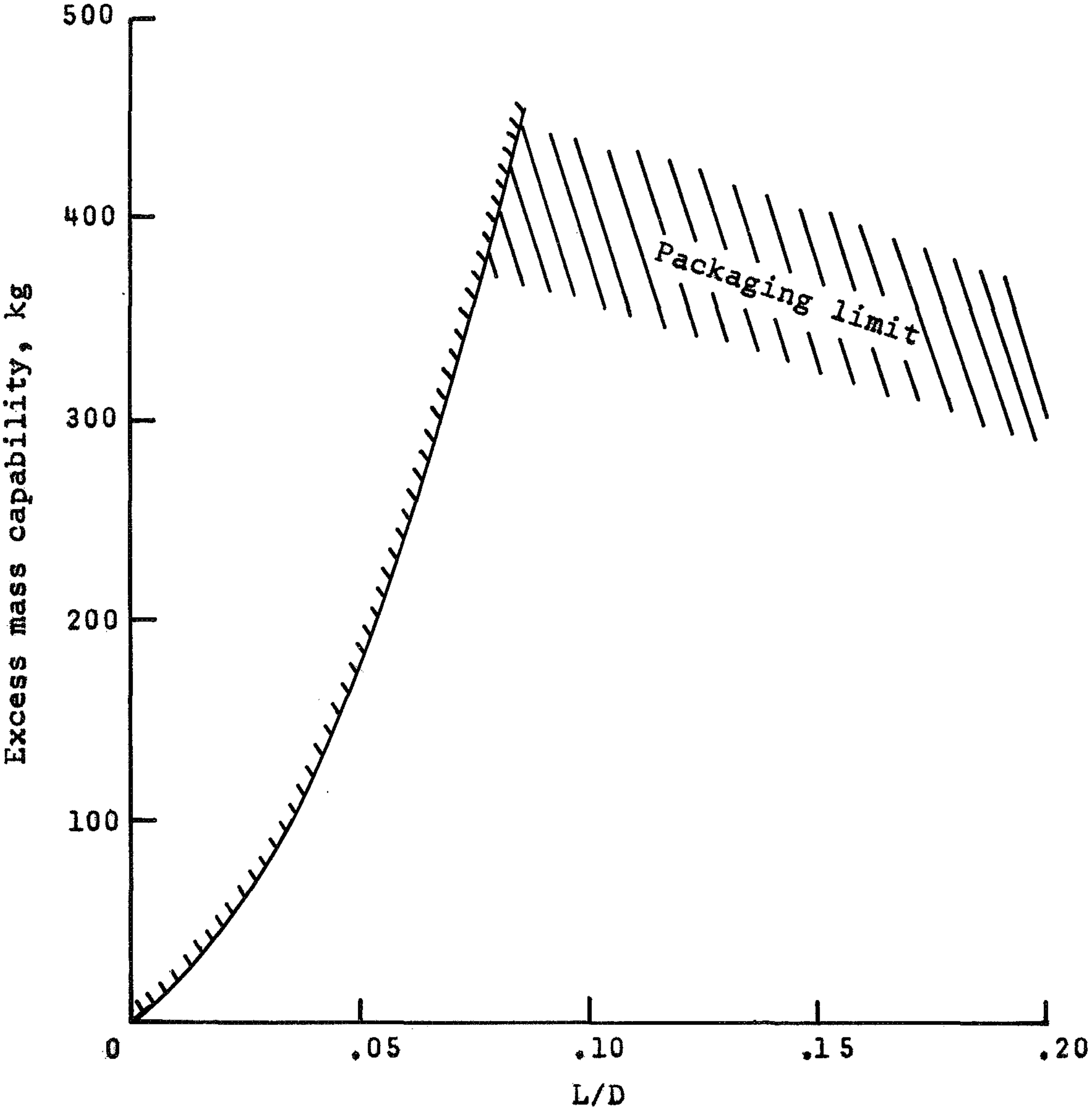


Figure 11.- Out-of-orbit weight capability above the baseline 1973 mission design. V_e = 4.6 km/s; $-\gamma_e = 16^0 \pm 2^0$; M_d = 2 at h = 5.1 km; model A atmosphere.

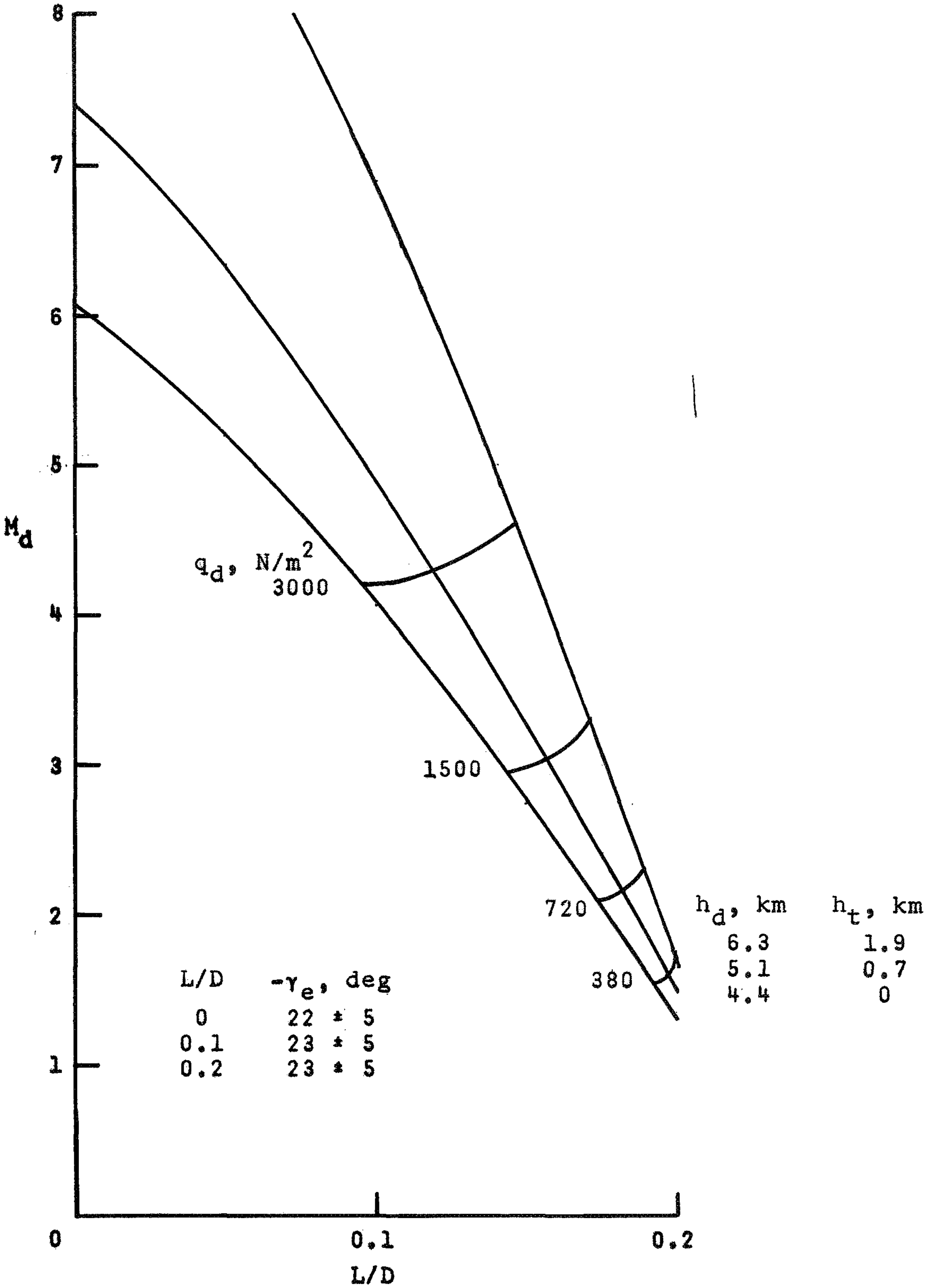


Figure 12.- Parachute deployment conditions for direct entry. V_e = 5.7 km/s; m/A = 88 kg/m^2; model A atmosphere.

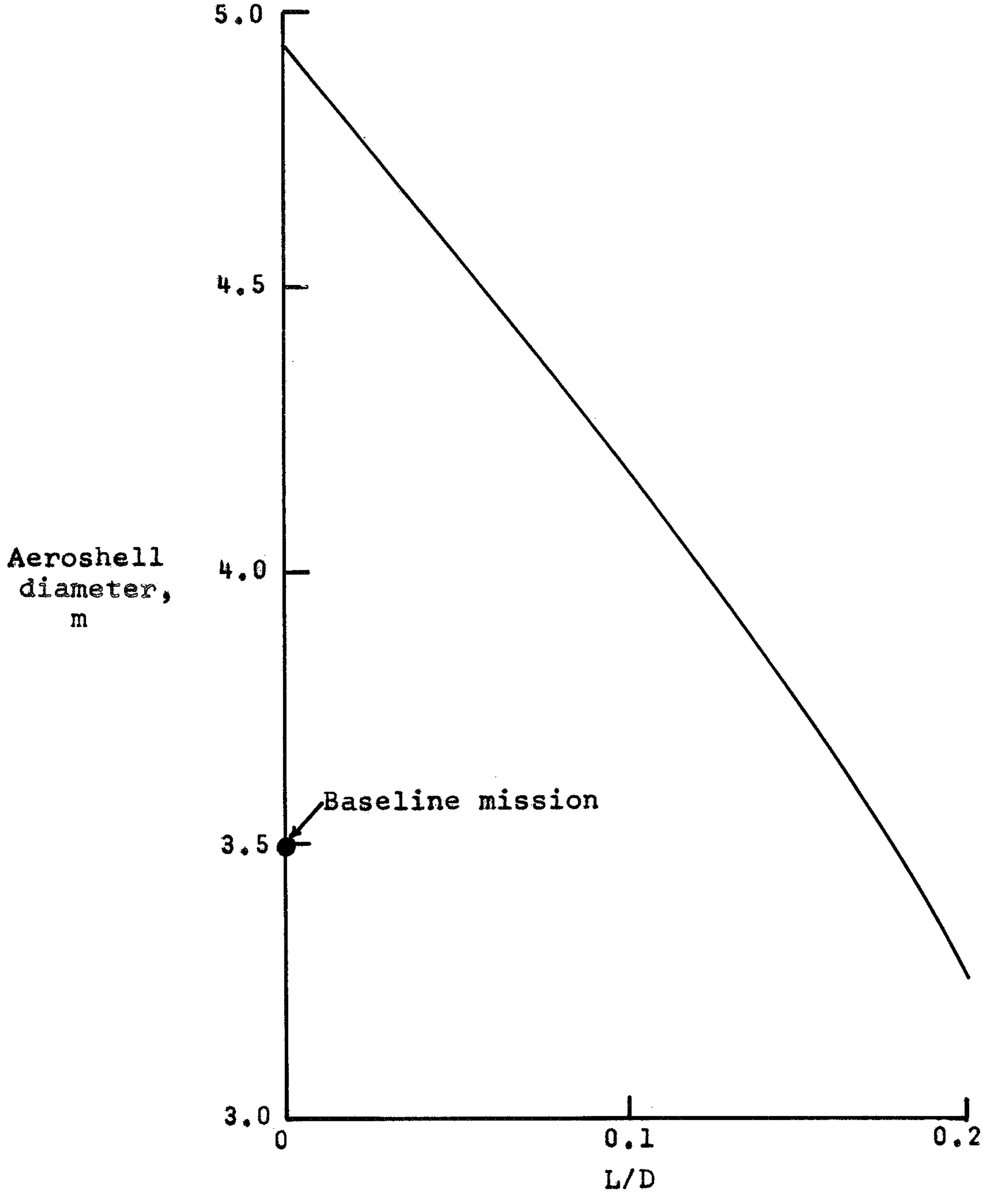


Figure 13.- Required aeroshell diameter for direct entry. V_e = 5.7 km/s; $\Delta\gamma_e = \pm 5^0$; M_d = 2 at h_d = 5.1 km; model A atmosphere.

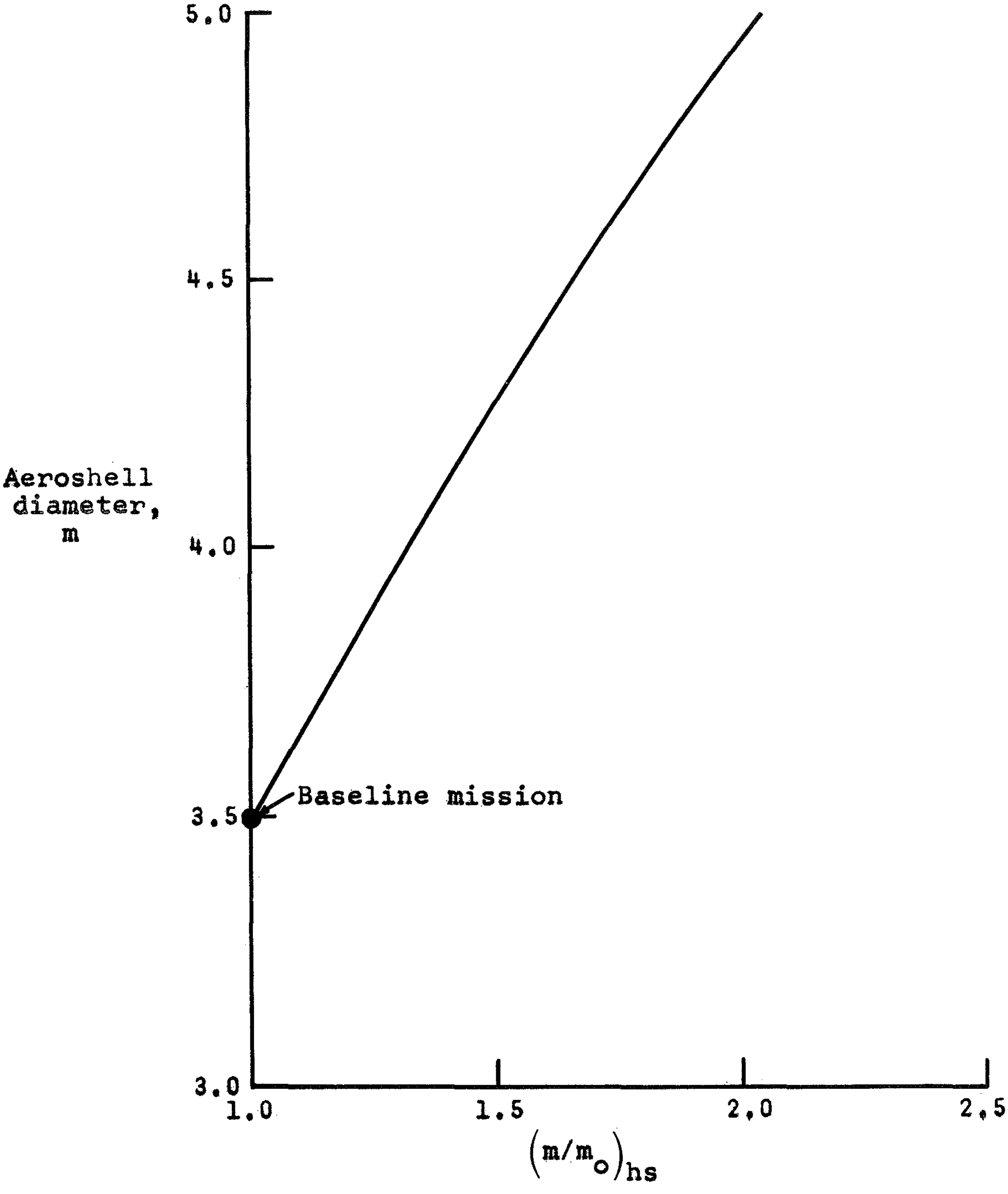


Figure 14.- Effect of aeroshell diameter on heat-shield weight. $V_e = 5.7$ km/s; $\Delta\gamma_e = \pm 5^0$; $M_d = 2$ at $h_d = 5.1$ km; model A atmosphere.

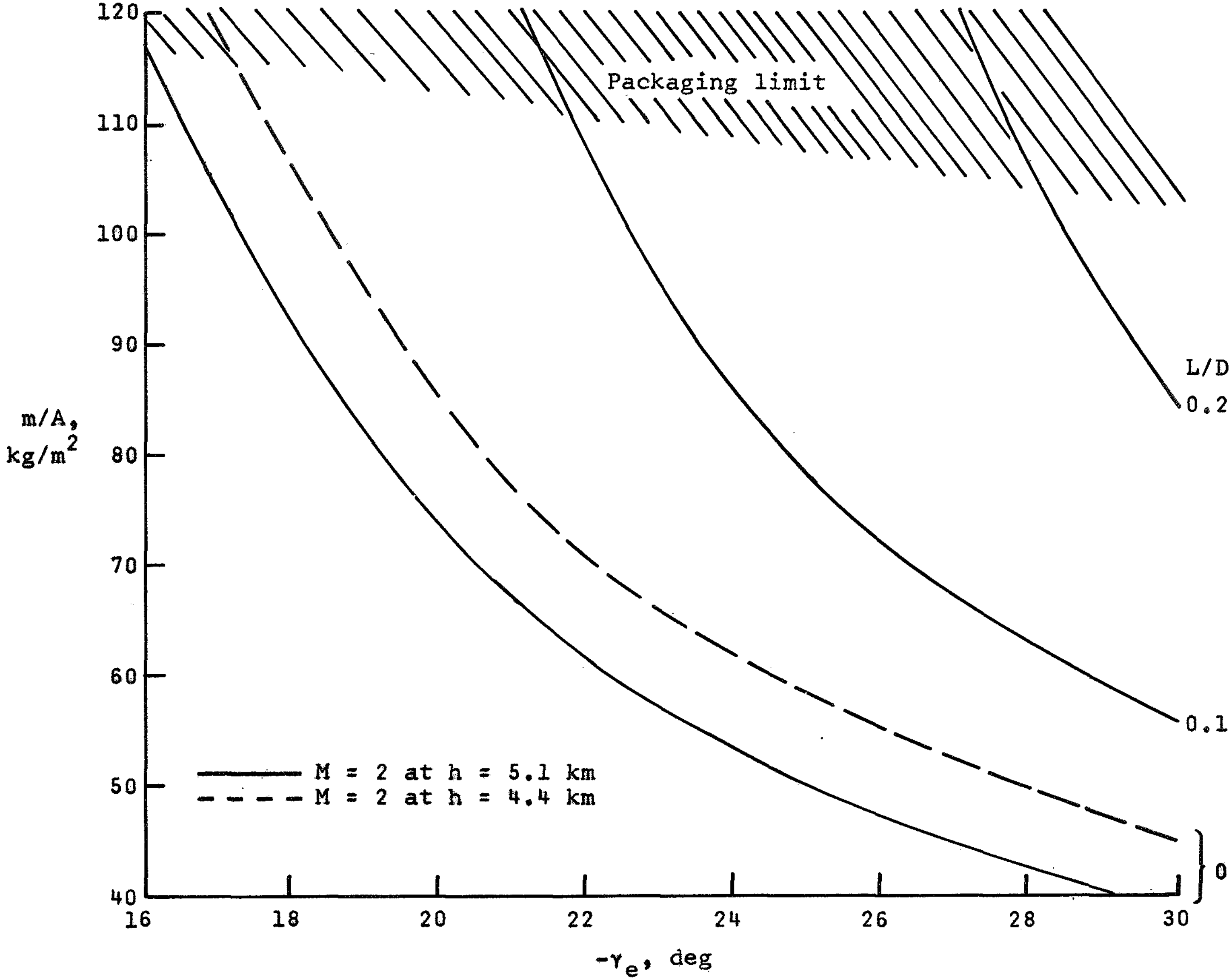


Figure 15.- Effect of entry angle on m/A for direct entry. V_e = 5.7 km/s; model A atmosphere.

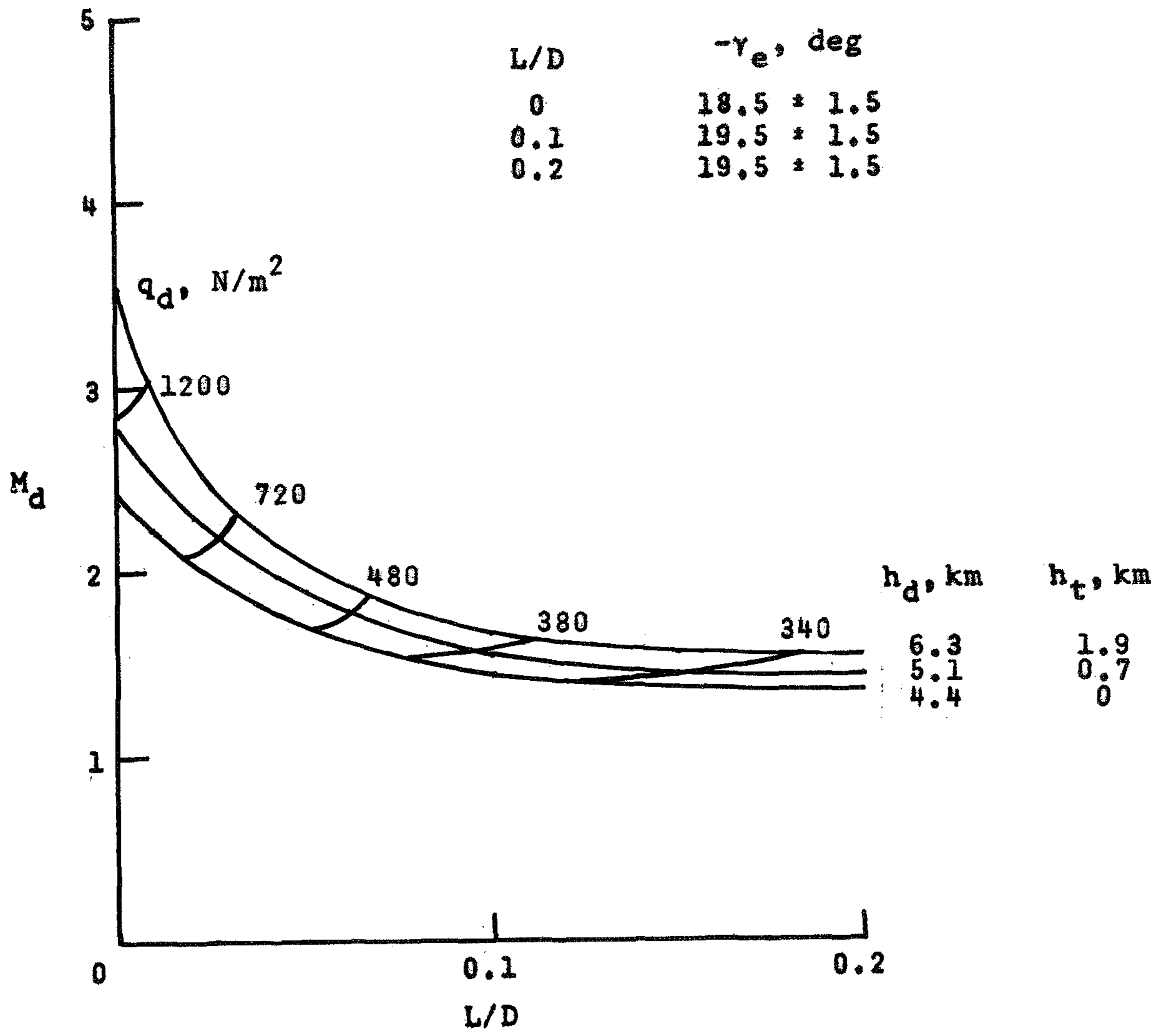
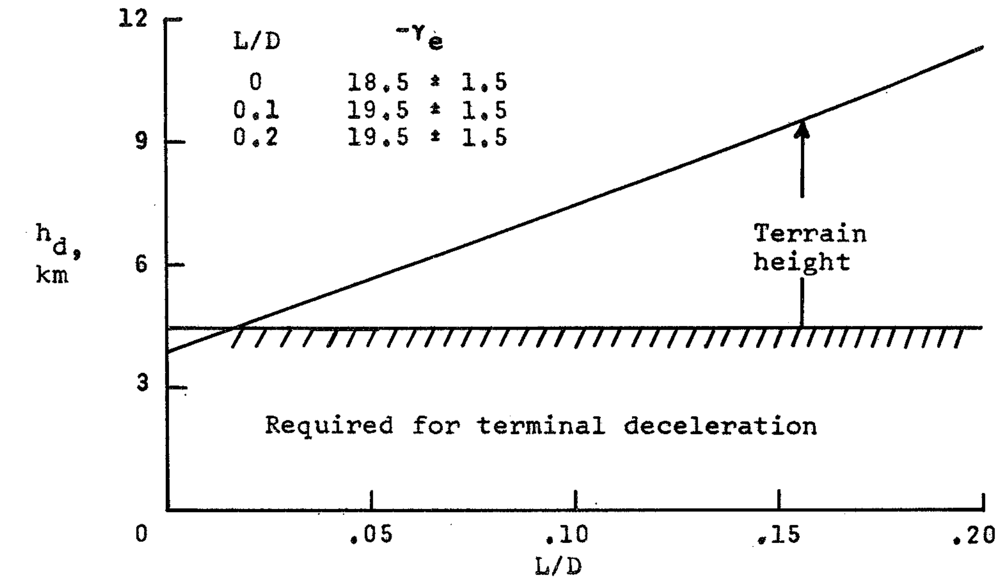
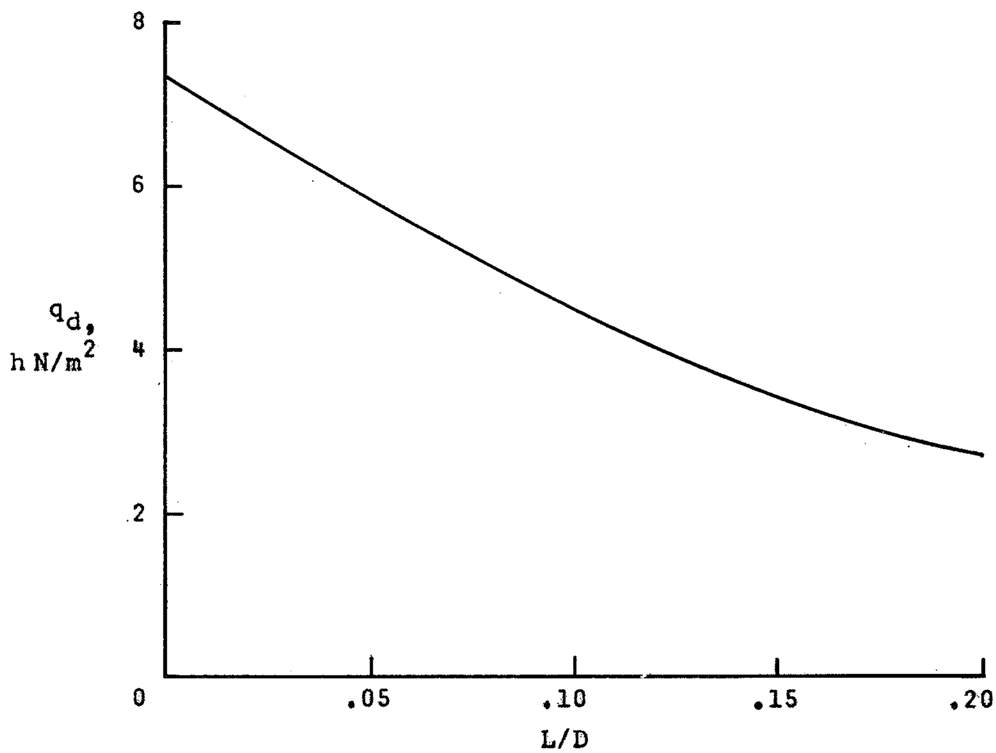


Figure 16.- Parachute deployment conditions for direct entry with approach guidance. V_e = 5.7 km/s; m/A = 88 kg/m^2; model A atmosphere.



(a) Maximum terrain altitude.



(b) Dynamic pressure at maximum altitude.

Figure 17.- Maximum terrain-height capability with corresponding dynamic pressure for parachute deployment at a Mach number of 2 during direct entry. V_e = 5.7 km/s; m/A = 88 kg/m^2; model A atmosphere.

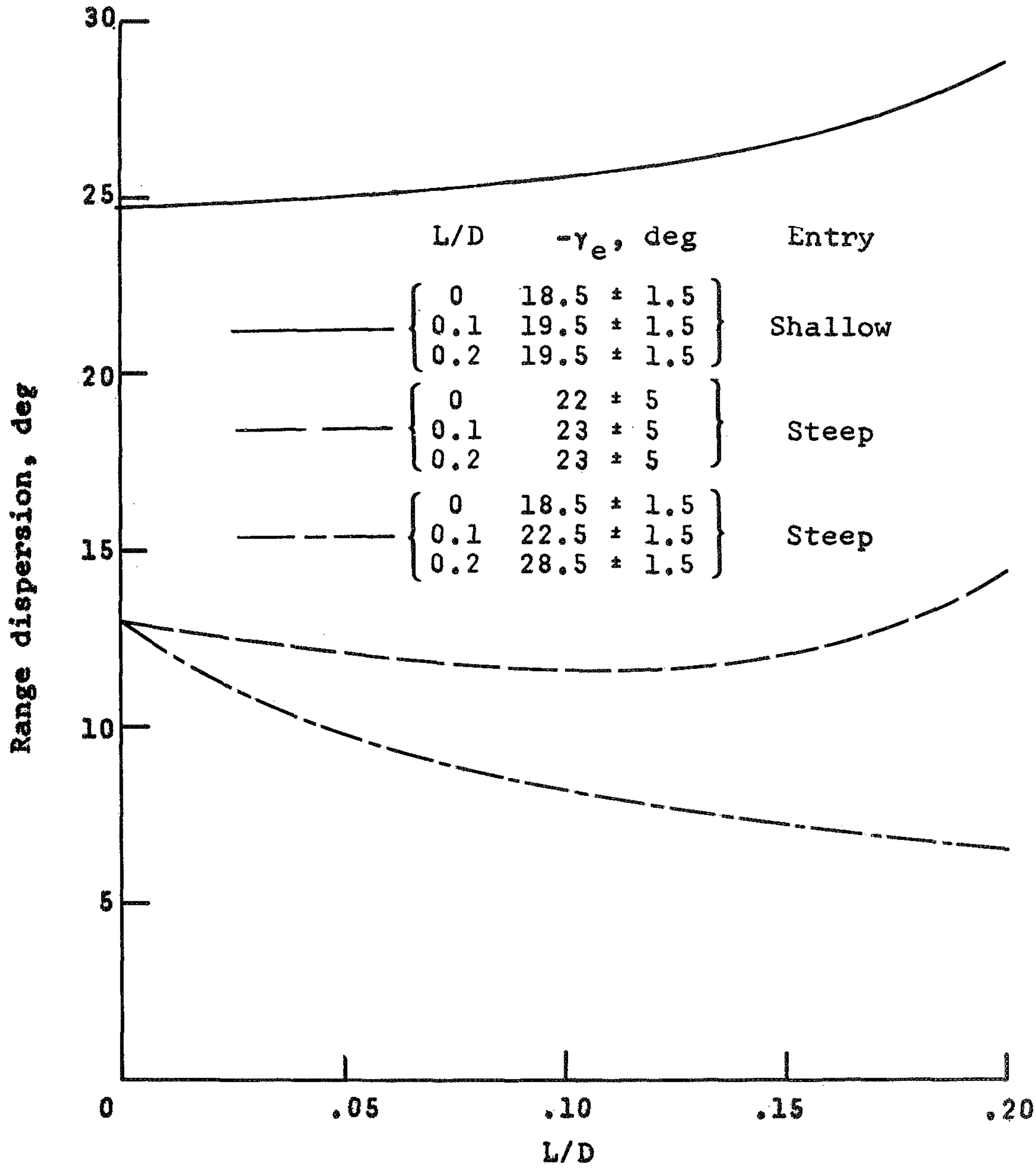


Figure 18.- Direct-entry range dispersion. V_e = 5.7 km/s; m/A = 88 kg/m^2.

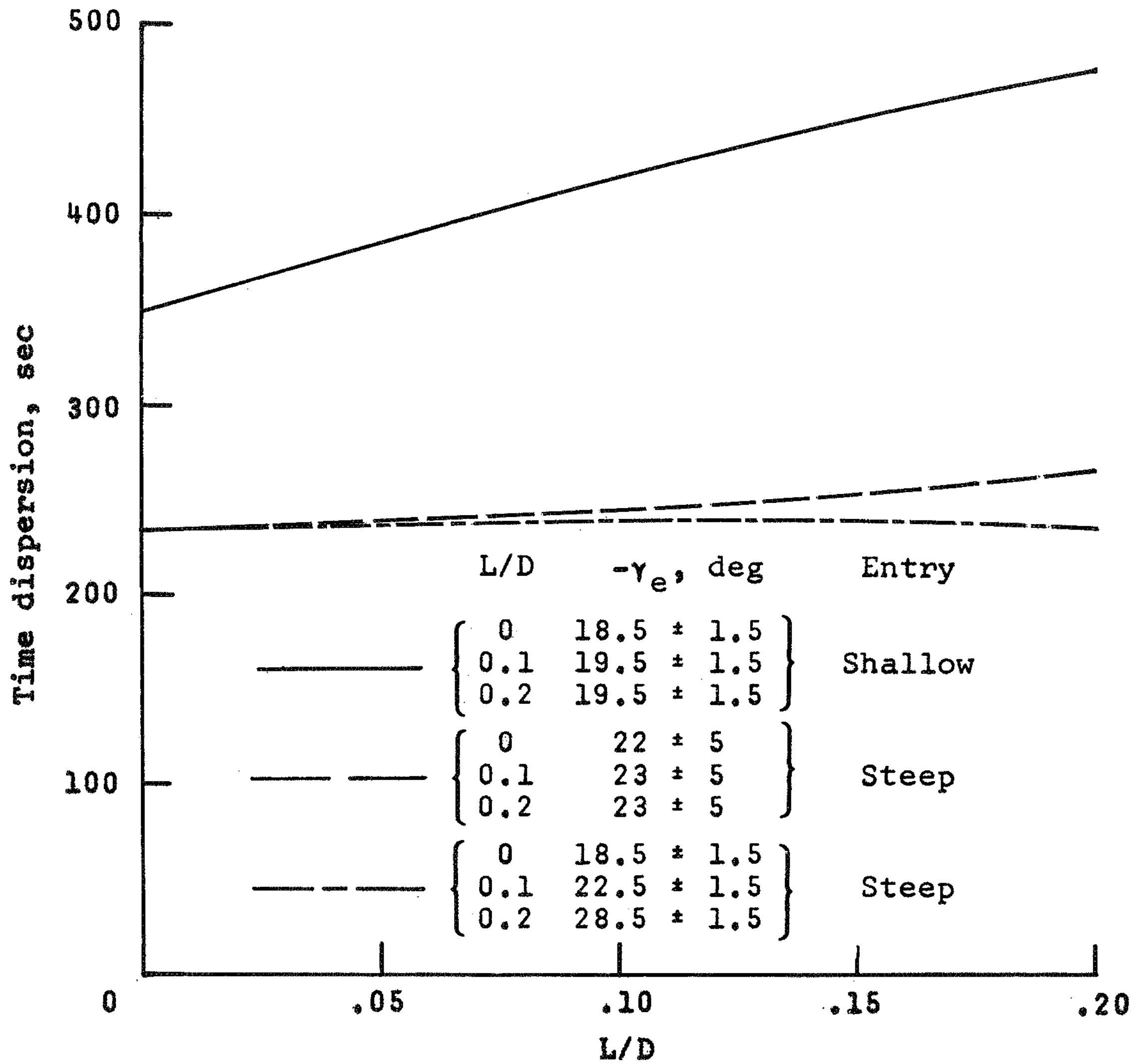


Figure 19.- Direct-entry time dispersion. V_e = 5.7 km/s; m/A = 88 kg/m^2.

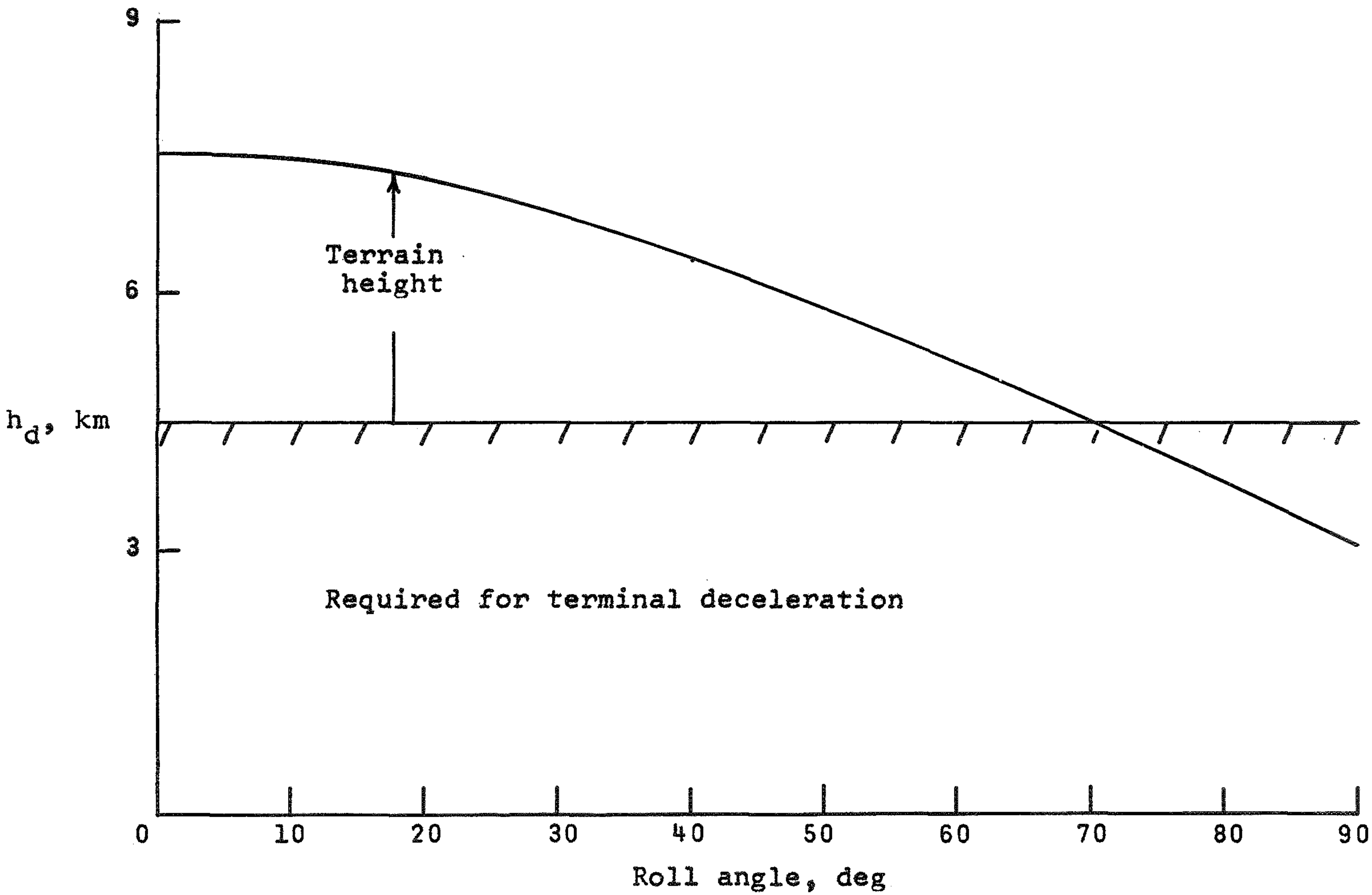


Figure 20.- Effect of roll angle on parachute-deployment altitude for direct entry. $L/D = 0.1$; $V_e = 5.7$ km/s; $m/A = 88$ kg/m^2; $-\gamma_e = 18^\circ \pm 1.5^\circ$; $M_d = 2$; model A atmosphere.

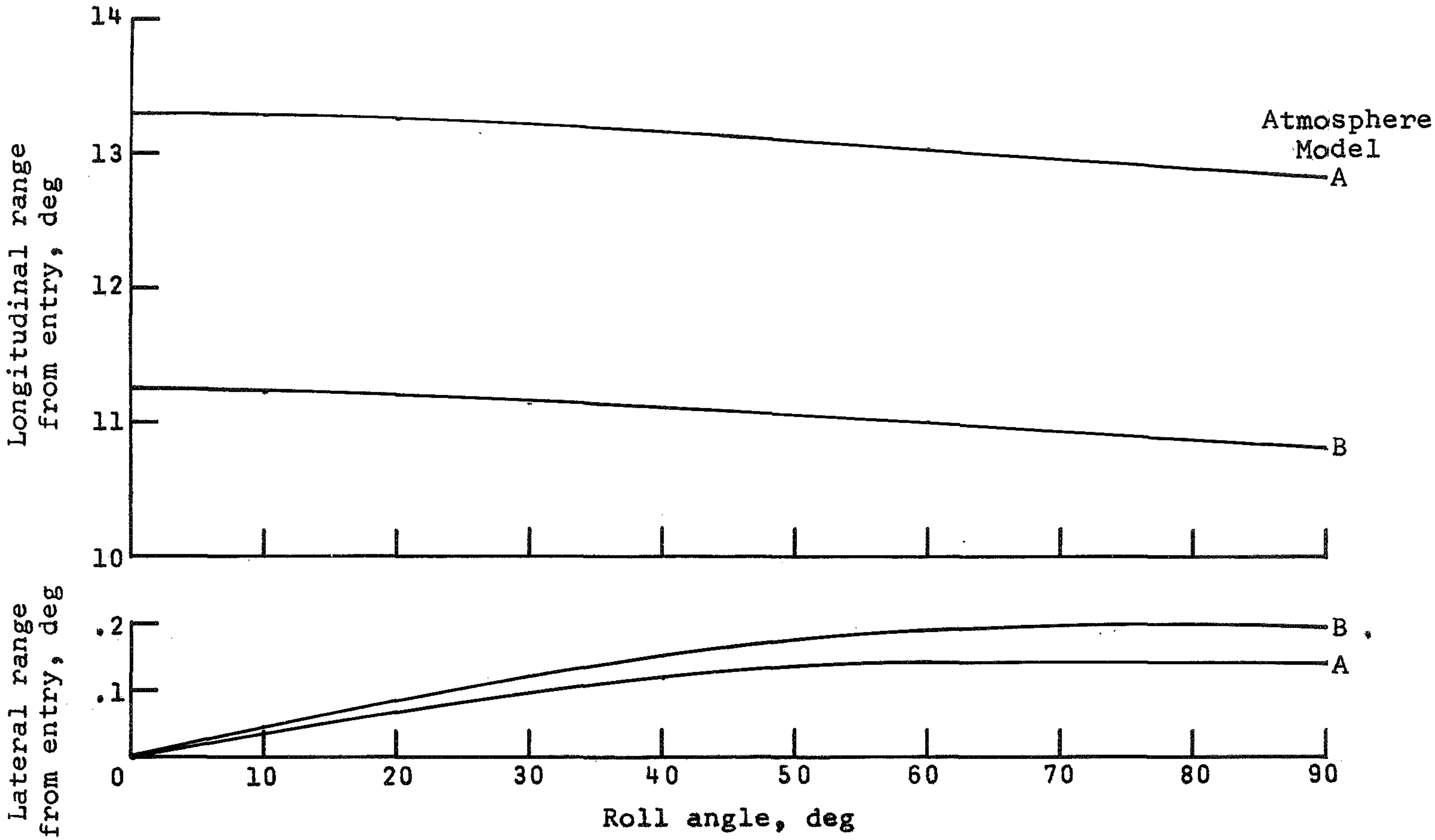


Figure 21.- Effect of roll angle on range for direct entry. $L/D = 0.1$; $V_e = 5.7$ km/s; $-\gamma_e = 18^0 \pm 1.5^0$; $m/A = 88$ kg/m^2.

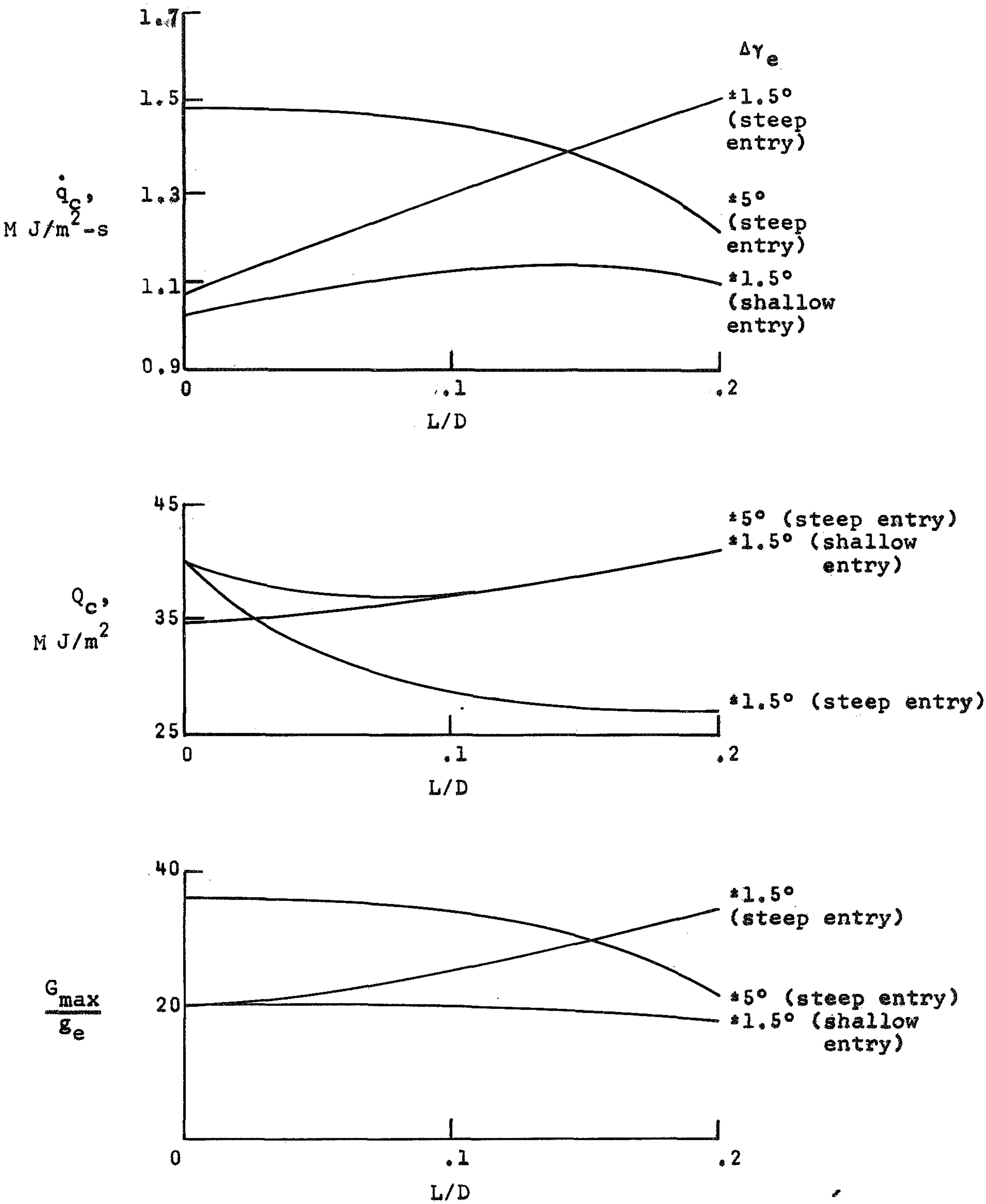


Figure 22.- Heating and deceleration characteristics for direct entry. V_e = 5.7 km/s; m/A = 88 kg/m^2; model A atmosphere for $\dot{q}_c$ and G_{max}/g_e and model B atmosphere for Q_c.

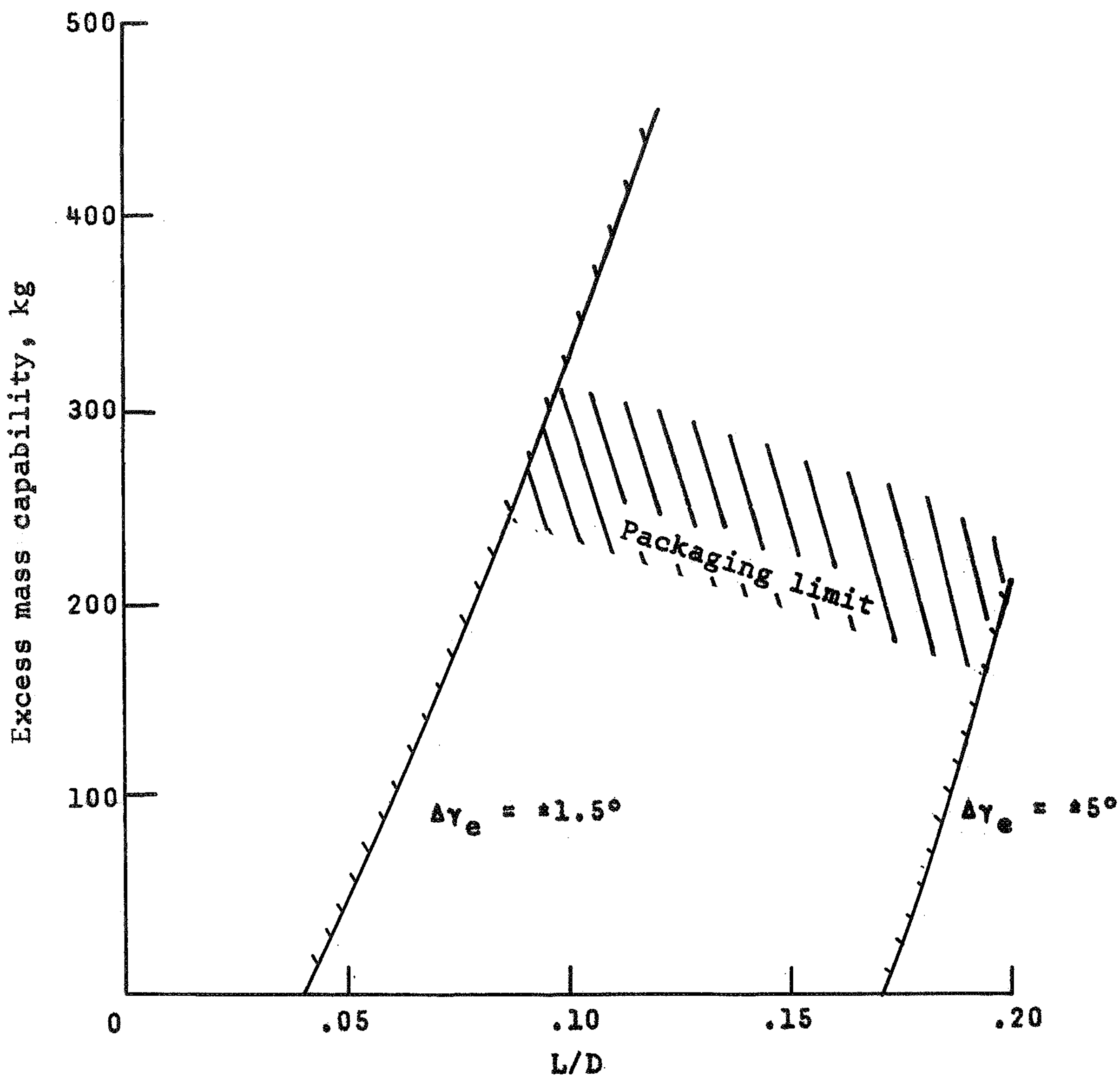


Figure 23.- Direct-entry mass capability above the present 1973 design. $M_d = 2$ at $h = 5.1$ km; vehicle diameter, 3.5 m.

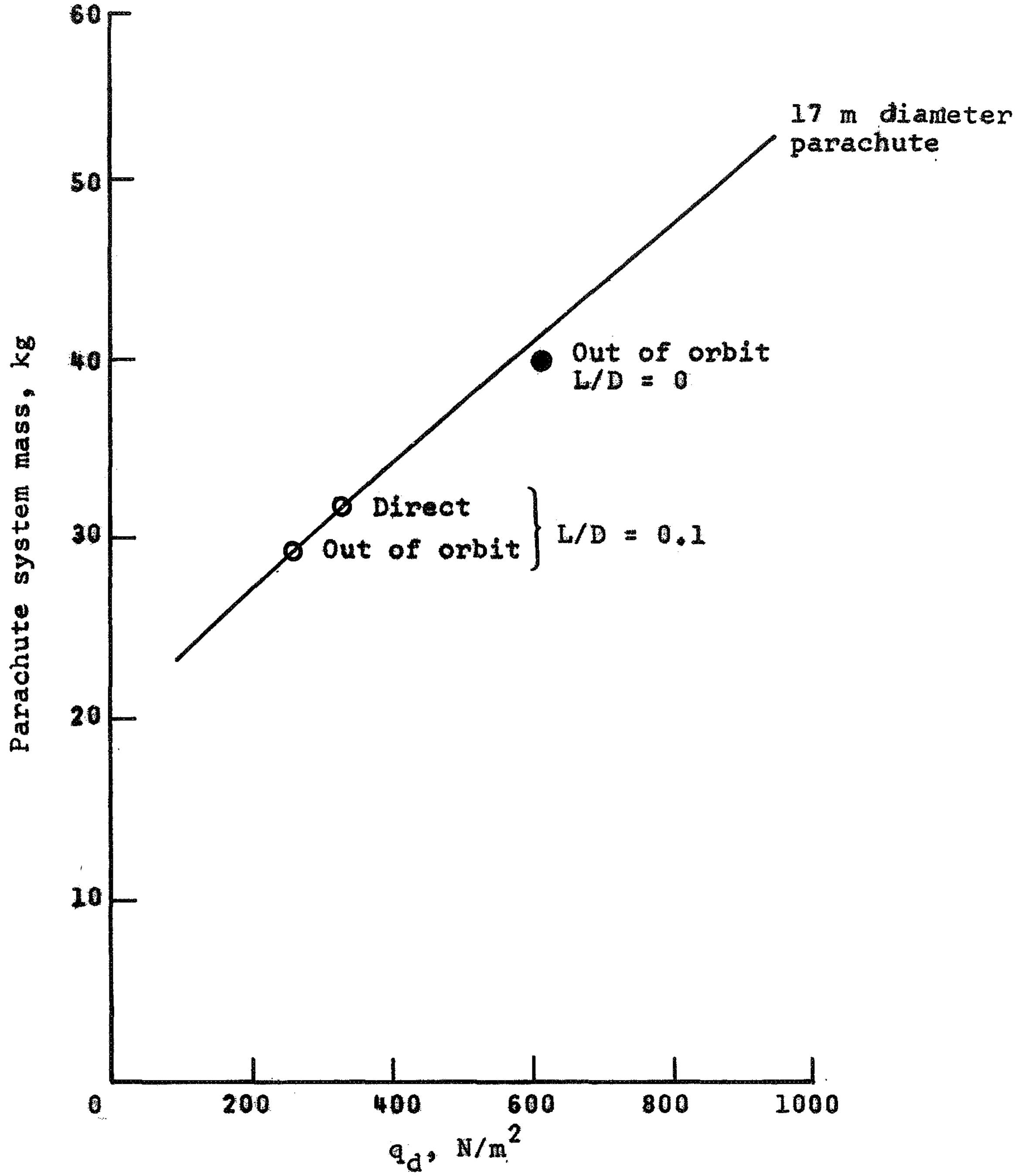


Figure 24.- Effect of dynamic pressure on parachute system.

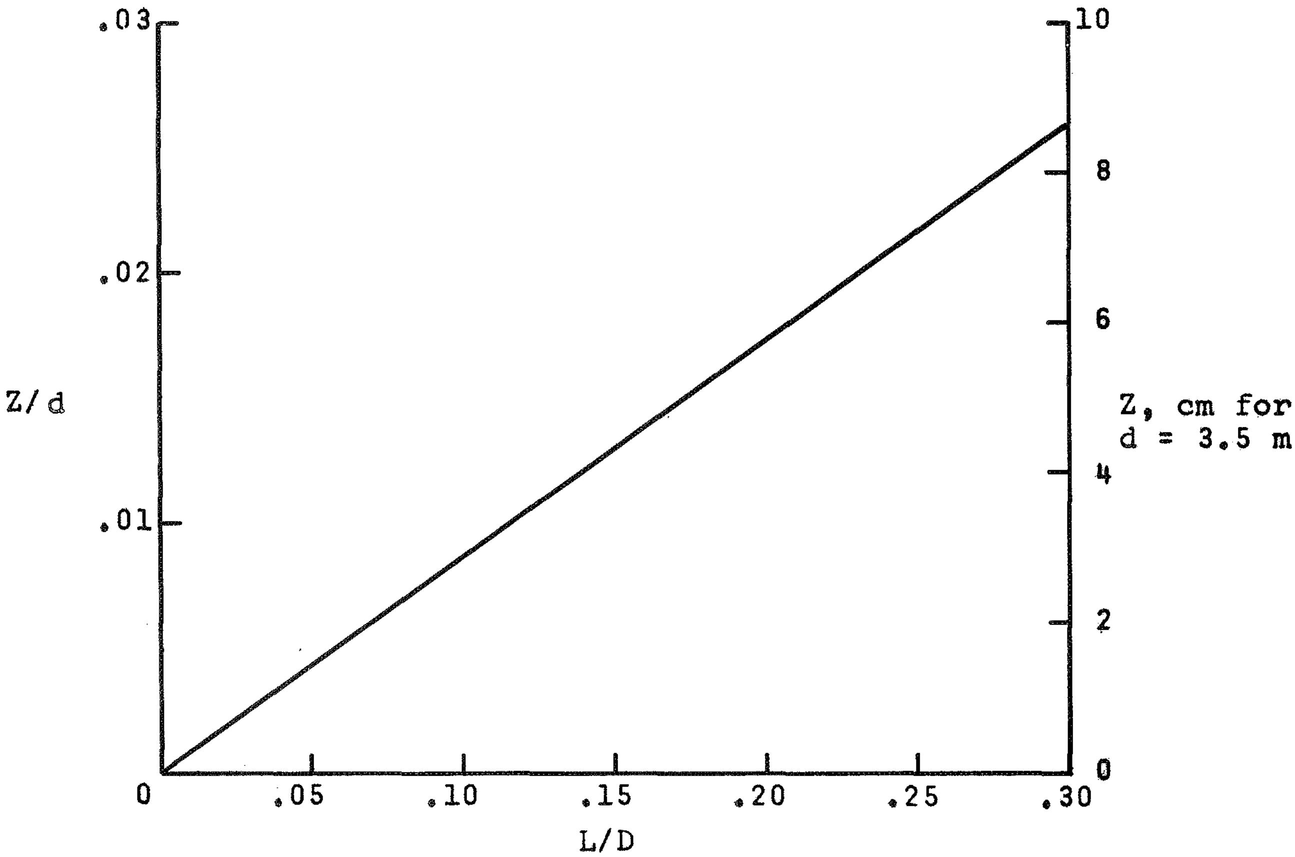


Figure 25.- Center-of-gravity offset for 140° blunted cone.

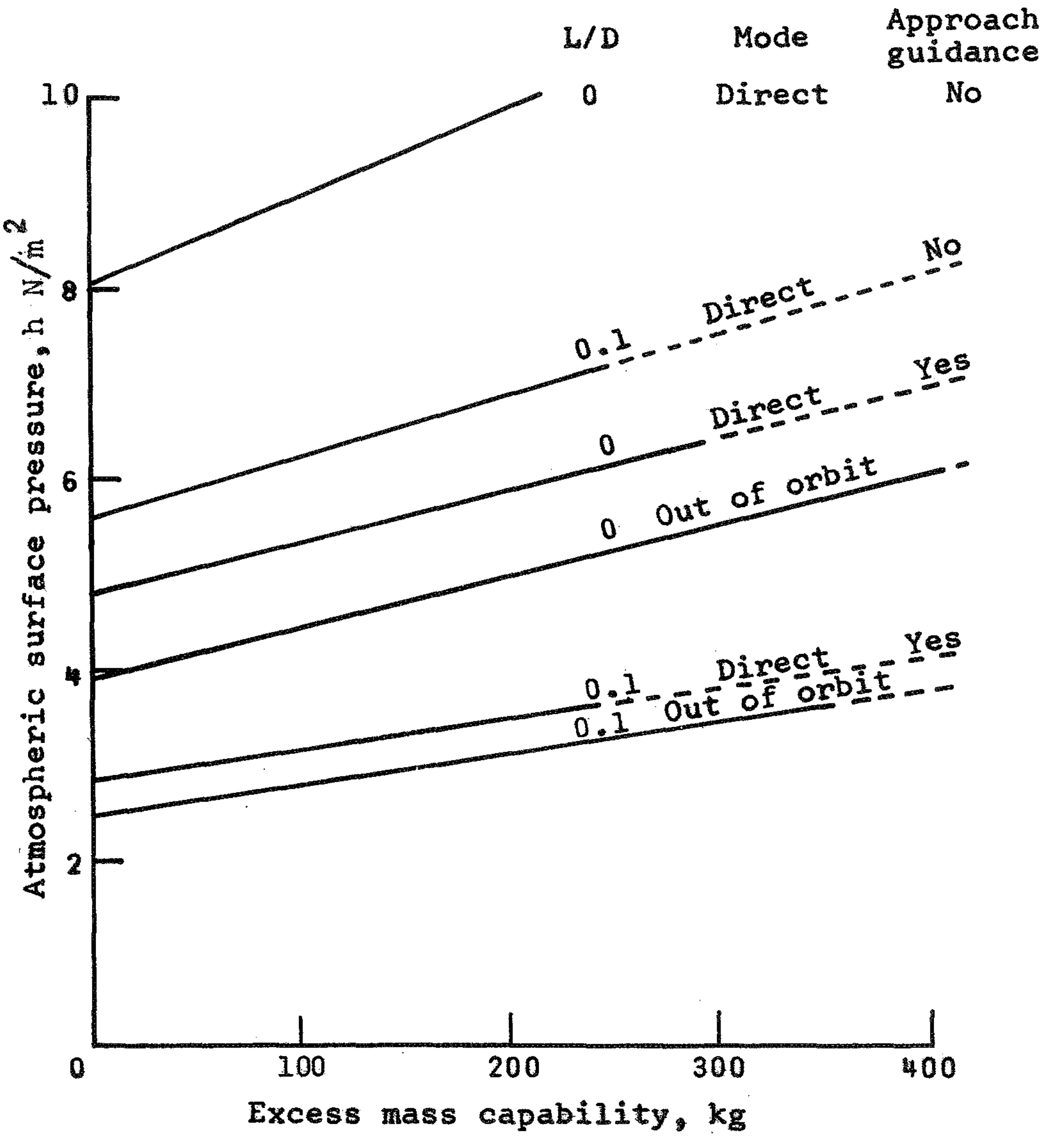


Figure 26.- Effect of surface pressure on payroll growth potential.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS A
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 15
Postal Manual) Do Not Retu

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546